SPECIES STATUS ASSESSMENT REPORT FOR Kuenzler Hedgehog CACTUS *Echinocereus fendleri* Englemann variety *kuenzleri* (Castetter, Pierce and Schwerin) L. Benson

Photograph - Frank Weaver, U.S. Fish and Wildlife Service

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Table of Contents

List of Tables

List of Figures

Executive Summary

Kuenzler's hedgehog cactus (*Echinocereus fendleri* var. *kuenzleri*)(EFK) is a small cactus that is endemic to the northwest side of the Sacramento, and Capitan Mountains in Lincoln County, New Mexico to middle of the Guadalupe Mountains in Eddy County, New Mexico. It was federally listed as endangered in 1979 (U.S. Fish and Wildlife Service [Service] 1979:61924-61927) as *Echinocereus kuenzleri*. Benson (1982: 631) subsequently reduced it to infraspecific rank as *E. fendleri* var. *kuenzleri*. At the time of listing, fewer than 200 individuals had been documented at two locations. Surveyors have since found at least 4,330 EFK during 1976 to 2015 inventories at 32 locations.

The most recent EFK assessment found 56.2 percent (18) occupied locations were stable to stable/upward trending (numbers were up by more than 20 percent), 31.3 percent (10) were stable/downward to downward trending (numbers were down by more than 20 percent), and remaining 12.5 percent (6) were undetermined (NMNH 2017: 11). The downward trends were often attributed to recent fire activity.

We developed a suitable habitat model based on the soil types, elevation, slope, aspect, and average annual rainfall of documented populations. This model predicts that 38,136 ha (94,238 acres) of potential habitat occur in the currently known range. Based on this model and density calculations from nearby populations we estimate that the EFK population is about 11,000 to 20,000 individuals.

We project what the viability of EFK could be under three scenarios. The "better than expected" scenario represents improvements over current conditions. The "moderate" scenario represents the most likely conditions if current trends continue. The "worse than expected" scenario represents deteriorating conditions. The overall condition under the moderate scenario (continuing conditions) is moderate to high.

I. Introduction

Kuenzler’s hedgehog cactus (*Echinocereus fendleri* var. *kuenzleri*)(EFK) is a small cactus that is endemic to the northwest side of the Sacramento, and Capitan Mountains in Lincoln County, New Mexico to middle of the Guadalupe Mountains in Eddy County, New Mexico. It was federally listed as endangered in 1979 (U.S. Fish and Wildlife Service [Service] 1979: 61924-61927) as *Echinocereus kuenzleri*. At that time, fewer than 200 individuals had been documented at two locations. Botanists have since found at least 4,330 EFK during 1976 to 2015 inventories. The number of plants in these survey areas is likely greater not only because survey intensity is less than 100 percent of the potentially occupied habitat, but importantly because non-flowering cacti are difficult to detect and often do not flower at the same time. Several surveyors for EFK state that the numbers of sightings under-represent the current numbers of cacti present (Forest Service 1989a: 2; Debruin 1992: 2; Sivinski 1999: 2; Chauvin et al 2012: 2).

The Service proposed EFK for downlisting in 2017 under the Endangered Species Act (ESA) (Service 2017: entire). This Species Status Assessment (SSA) report is a comprehensive biological status review to inform a decision about the species’ status under the ESA and to guide future conservation efforts. This SSA report will also provide the background information to guide future actions and documents, which may include additional listing rules, revised recovery plans, 5-year reviews, and section 7 consultations. We will update this SSA as new information becomes available.

The SSA framework (Figure 1, Service 2016a: entire) summarizes the information assembled and reviewed by the Service, incorporating the best available scientific and commercial data, to conduct an in-depth review of a species’ biology and threats, evaluate its biological status, and assess its resources and conditions needed to maintain long-term viability. For the purpose of this assessment, we define the viability of EFK as its ability to sustain populations in the wild beyond the end of a specified time period. Using the SSA framework, we consider what the species needs to maintain viability through an assessment of its **resilience**, **redundancy**, and **representation**.

• **Resilience** refers to the population size necessary to endure stochastic environmental variation (Shaffer and Stein 2000: 308–310). Resilient populations are better able to recover from losses caused by random variation, such as fluctuations in recruitment (demographic stochasticity), variations in rainfall (environmental stochasticity), or changes in the frequency of wildfires.

• **Redundancy** refers to the number and geographic distribution of populations or sites necessary to endure catastrophic events (Shaffer and Stein 2000: 308–310). As defined here, catastrophic events are rare occurrences, usually of finite duration, that cause severe impacts to one or more populations. Examples of catastrophic events include tropical storms, floods, prolonged drought, and wildfire. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a sufficient margin of safety to withstand or recover from catastrophic events.

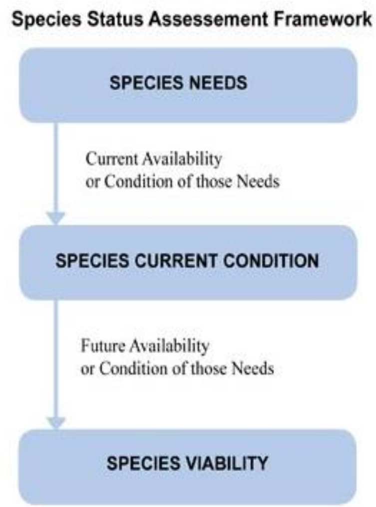

Figure 1. Species Status Assessment Framework

• **Representation** refers to the genetic diversity, both within and among populations, necessary to conserve long-term adaptive capability (Shaffer and Stein 2000: 307–308). Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is able to adapt to environmental changes (natural or human caused) and to colonize new sites.

In summary, this SSA report is a scientific review of the available information related to the biology and conservation status of EFK. It does not provide or pre-determine the Service's decision that the EFK does, or does not, warrant protection under the ESA. The Service will make that decision after reviewing this document, along with the supporting analyses, other relevant scientific information, and all applicable laws, regulations, and policies, and the results of the decision will be announced in the *Federal Register*.

Throughout this document, the first uses of scientific and technical terms are underscored with dashed lines; these terms are defined in the glossary in Appendix A. Appendix B describes our methods to model habitat and estimate the global population size, based on quantitative data from surveys.

II. Species Information

II.1. Description

EFK grows as solitary stems or 1 to 4 in a cluster, rarely as many as 8 stems; mature stems are conical to short cylindroid, 10–15 centimeters (cm) (4–6 inches [in]) tall, rarely to 30.5 cm (12 in) tall, and 5.1–10.2 cm (2–4 in) in diameter; ribs 9 to 12, usually 10; tubercles conspicuous; spines sharply pointed, angular in cross section, bulbous and fused together at base, central spine usually absent, sometimes one, light to dark brown or dull black 2.2–2.9 cm (0.87–1.14 in) long; radial spines 2–6, mostly 4–5 stout, mostly curved, 0.6–2.2 cm (0.25–0.87 in) long, typically contorted, white and chalky textured; flowers apical 5.7–10 cm (2.25–4.0 in) in length and diameter, tepals are magenta, usually with bands of green and darker color near center, usually pointed (Castetter et al. 1976: 77–78; Ferguson and McDonald 2006: 2). Baker (2007: 25) did not find fusion of the radial spines in the specimens he studied.

The few contorted, white, chalky-textured spines and large, magenta flowers separate the EFK from other cacti within the range. Other hedgehog cacti (*Echinocereus* spp.) either have red flowers or multiple central spines present that are gray to black (Benson 1981: 120–121; Weniger 1984: 10–15). *Echinocereus triglochidiatus* var. *triglochidiatus*, a common cactus in the area, can be differentiated by its red flower and lack of stripes on the larger spines, and large fuzzier, white areoles (Zimmerman 1995: 1).

II.2 Taxonomy

In 1976, EFK, in its New Mexico and Mexico locations, was proposed as endangered under the name *Echinocereus hempelii* (Service 1976: 24,536). Later in 1976, *Echinocereus kuenzleri* was described as a new species specifically for the New Mexico population of what had previously been called *E. hempelii* (Castetter et al. 1976: 77). *Echinocereus hempelii*, presently referred to as *E. fendleri var. hempelii* (also taxonomically uncertain at this time), is known only from a few locations in Chihuahua, Mexico (Felix et al. 2014: 65). EFK was originally listed in 1979 as *Echinocereus kuenzleri* (Service 1979: 61,524). Benson (1982: 631) subsequently reduced it to infraspecific rank as *E. fendleri* var. *kuenzleri*. Based on this nomenclatural change we accepted the variety *E. fendleri* var. *kuenzleri* and officially changed the name on the list of Endangered and Threatened Wildlife and Plants in 1984 (Service 1984: 21). Anderson (2001: 236) was uncertain whether this variety should be recognized taxonomically. Felix et al. (2014: 105) elevated EFK to subspecies rank.

The taxonomic standing of a named variety depends upon a consensus of opinion and the informed judgment of those taxonomists who publish their opinions. Zimmerman (1995: 1) believed the variety *kuenzleri* was very closely related to typical *E. fendleri*, such that it's just barely a valid taxon and postulated that variety *kuenzleri* is simply a neotenous form of *E. fendleri* that retains juvenile stem and spination characteristics into adulthood. Zimmerman and Parfitt (2003: 157) reduced variety *kuenzleri* to a synonym of the common and widespread *E. fendleri* var. *fendleri* because of its neotenous features.

Baker (2007: entire) examined the morphological variation in the varieties of *Echinocereus fendleri*, and assigned *kuenzleri* as a separate variety based on stem rib morphology and spine length and shape. Felix et al. (2014: entire) published a morphological study of *Echinocereus fendleri* where they found that the structure, texture, and conformation of the spines were unique in *kuenzleri*, warranting subspecies status.

Echinocereus fendleri var. *kuenzleri* could be classified as 1) an infraspecific taxon representing a discrete geographic lineage worthy of nomenclatural recognition; 2) the same variety as *E. fendleri* var. *fendleri*; or 3) a trivial variant that should not have taxonomic status within the broader suite of unnamed varieties and falls under the species *E. fendleri* (Service 1979: 61,924; Zimmerman and Parfitt 2003: 164). *Echinocereus fendleri* var. *fendleri* exhibits variation throughout its range and occurs in scattered populations that are widespread but not abundant. It is known throughout the western portion of New Mexico, into Arizona, Colorado, and Texas, and in northern Mexico (Chihuahua, Sonora) (Zimmermann and Parfitt 2003: 164; Felix et al. 2014: 65). There does not appear to be any overlap between *E. fendleri* var. *fendleri* and *E. fendleri* var. *kuenzleri* though intermediate forms have been found in the Vera Cruz area (Northern Sacramento Mountains population) (Marron and Associates, Inc. 2000: 4.14–4.15) and along US 54 north of Carrizozo (west side of Sacramento Mountains (Blue Earth Ecological Consultants, Inc. [BEEC] 2002: 28–32). Based on this information, the Service maintains *E. fendleri* var. *kuenzleri* as a variety until further work can be done on the genetics of the taxon.

II.3. Life history: Growth, phenology, reproduction, and mortality

EFK is a perennial and reproduction is sexual (New Mexico Energy, Minerals, and Natural Resources Department [NMEMNRD] 1989: 106). There is no evidence of reproduction by bulbils, tubers, stolons or rhizomes and it does not appear to reproduce by vegetative fragmentation (BEEC 2002: 27).

Budding occurs in April and flowering normally occurs during the first half of May into early June. Warm years can initiate earlier flowering and cool springs may delay flowering until early June (BEEC 2002: 27). Flowers are large for the size of the plant. Fruits form in August and average 3-6 per plant (NMEMNRD 1989: 106). Fruits are bright red when mature, ovoid to cylindrical, may be over 5 cm (2 in) long, and are spiny with miniature versions of the stem spines. Each fruit can have as many as 1,050 seeds (NMEMNRD 1989: 106). Seeds are black and pitted. Greenhouse studies at Mesa Gardens in Belen, New Mexico, indicate EFK requires 21 degree Celsius (°C)(70 degree Fahrenheit [°F]) soil temperature and sufficient moisture for germination (NMEMNRD 1989: 106). Seeds have over 90 percent viability and can survive in the soil for at least 5 years (NMEMNRD 1989: 106). There is no known dormancy requirement (NMEMNRD 1989: 106).

Seed dispersal occurs during September and October by rodents, wind, and water (BEEC 2002: 27). Seed dispersal may be dependent on summer rainfall, average to above-average summer rainfall results in abundant fruit production, which prolongs good seed dispersal. Dry summers result in low fruit abundance, which are intensively consumed by rodents as soon as fruits mature. Only seeds that are not consumed are likely to survive to germinate (BEEC 2002: 27). The size class distribution of the population suggests that successful germination and growth into juvenile plants is rare (NMEMNRD 1989: 106).

Plants reach a diameter of 0.3, 0.9, and 1.8 cm (0.1, 0.4, and 0.7 in) at 1, 2, and 3 years of age, respectively (NMEMNRD 1989: 97). Growth averaged over all age classes was estimated at 1.4 cm (0.55 in) per year (NMEMNRD 1989: 100). By year 4 plants can exceed 4.0 cm (1.6 in) in diameter (NMEMNRD 1989: 97). Maximum diameter is about 10 cm (3.9 in) (NMEMNRD 1989: 97). The size class distribution indicates the population is dominated by 4+ year old plants with limited recruitment (NMEMNRD 1989: 97).

The Ft. Stanton populations appear to be at stasis with death rate balanced by recruitment ((NMEMNRD 1989: 102). A 10 percent annual mortality rate was estimated at the Fort Stanton population with greatest losses due to winter frosts (NMEMNRD1989: 107). Demographic information in the Southern Sacramento and Guadalupe populations is not available. In the absence of data we presume that mortality is equal across all populations. EFK does not flower and make fruit until it reaches 4 to 5 years of age (Sivinski 2007: 96)

Pollinator studies have not been performed for EFK. However, *Echinocereus*, *Opuntia*, *Ferocactus*, and other genera, have similar large, cup-shaped, brightly colored, day-blooming flowers, and are common throughout the Southwest. Little is known about the mode of pollination for EFK. However, similar southwestern cactus species are pollinated by medium-sized bees (Grant and Grant 1979: 85). Alexander (2017b: entire) documented a *Lithurgopsis* sp. in the megachilid family visiting an EFK flower. Megachilids are a cosmopolitan family mostly of solitary bees that feed on pollen and nectar, and are among the most efficient native pollinators (Michener 2007: 441)

II.4. Habitat and Ecology

Typical EFK habitat includes the lower fringes of the pinyon-juniper woodland from about 1,560 to 2,130 m (5,100 to 6,990 ft) elevation with an average of 180 frost-free days and annual precipitation of about 41 cm (16 in) (NMEMNRD1989: 91; BEEC 2002: 27). Occupied habitat consists of gentle slopes (15 to 60 percent) or benches with gravelly to rocky soils and southern, eastern, and western exposures (NMEMNRD1989: 93–94).

Although these observations accurately describe the type locality, observation data from population surveys by New Mexico Natural Heritage was analyzed, and used to confirm or distinguish occupied habitat characteristics. Four population centers are defined within the EFK range, Northern Sacramento population, Southern Sacramento population, Northern Guadalupe population, and Southern Guadalupe population. The Guadalupe populations were combined for the analysis due to small population numbers in the Northern Guadalupe population and their geographic proximity. The habitat characteristics (soil, elevation, aspect, and slope) from the populations were analyzed to determine if similarities or differences exist between populations.

II.4.1. Vegetation Community

EFK are found between the vegetation communities Great Basin-Conifer Woodlands (Brown 1982: 52, 115) – Coniferous-Mixed Woodlands (Dick-Peddie 1993: 87) and the Plains Mesas Grasslands to the north and Desert Grasslands to the south (Brown 1982: 104; Dick-Peddie 1993: 106). Woodlands differ from grasslands not only in vegetative composition but also climatic conditions with more days below freezing in the woodlands. The Plains Mesas Grasslands differs from the Desert Grasslands in having more scrub invasion.

Juniper (*Juniperus* spp.) encroachment into the grasslands due to fire suppression and grazing has changed the vegetation community in the region occupied by EFK over the last 100 years (Gebow and Halvorson 2004: 4).

The associated vegetation community is more specifically described as a shrubby grassland and juniper savanna with tree cover varying from 2 to 25 percent, and grasses being the dominant vegetative cover from 25 to 40 percent (Sivinski 1999: 1–2).

At Ft Stanton dominant plant cover in EFK study plots was grama grasses (*Bouteloua* spp.), scarlet beeblossom (*Oenothera suffrutescens*), and rose heath (*Chaetopappa ericoides*) (NMEMNRD 1989: 104–105).

II.4.2. Soils

EFK can be found in soil composed mostly of sand, silt, and a smaller amount of clay particles (loam), containing 35 percent or more (by volume) of rock fragments, cobbles, or gravel (skeletal). This combination of particles and small rock fragments allows for rapid soil drainage. The soil depth ranges from very shallow to very deep, derived from limestone, sandstone, sedimentary rock, igneous rock, or mixed sources (Soil Survey Geographic Database [SSURGO] 2014). Thirty one soil series were identified with EFK observations (Appendix B). The Northern Sacramento, Southern Sacramento, and Guadalupe populations contain 16, 4, and 11 soil series respectively. Table 1 lists the dominant soils series by population.

Table 1. Dominant soil series by Kuenzler's hedgehog cactus population.[1]

Soil Series	No. Observed
Northern Sacramento Mountains	
Romine extremely gravelly loam, 8 to 25 percent slopes	1819
Pena-Dioxice complex, moderately sloping	819
Hightower-Oro Grande complex, moderately steep	491
Southern Sacramento Mountains	
Deama-Rock outcrop complex	627
Guadalupe Mountains	
Deama gravelly loam, 2 to 15 percent slopes	325
Deama-Rock outcrop complex, 26 to 50 percent slopes	313
Deama gravelly loam, 0 to 3 percent slopes	241
Ector stony loam, 0 to 5 percent slopes	231
Rock outcrop-Deama complex, 20 to 50 percent slopes	191
Montecito loam, 0 to 6 percent slopes	163

[1]Soil types use percent slope and GIS derived slope are in degrees.

In the Northern Sacramento Mountains population three soil types accounted for 93 percent of EFK observations (Table 1). One soil type, Deama-Rock outcrop complex, dominated (99 percent) the Southern Sacramento Mountains population habitat (Table 1). The Guadalupe Mountains population habitat was more variable with six soil types accounting for 86 percent of the observation (Table 1). These soils are primarily Mollisols (Ustolls) that are basic-rich, calcareous derived supporting grasslands and used as rangelands (Natural Resources Conservation Service 1999: 601).

II.4.3. Elevation, Aspect, and Slope

The Northern Sacramento population ranges in elevation from 1,754–2,229 m (5,754–7,312 ft) (Figure 2). EFK is found on gentle to moderately steep slopes (slope range 0.5–30.6 percent) with mainly southeastern, eastern and southern exposures (Figures 3 and 4).

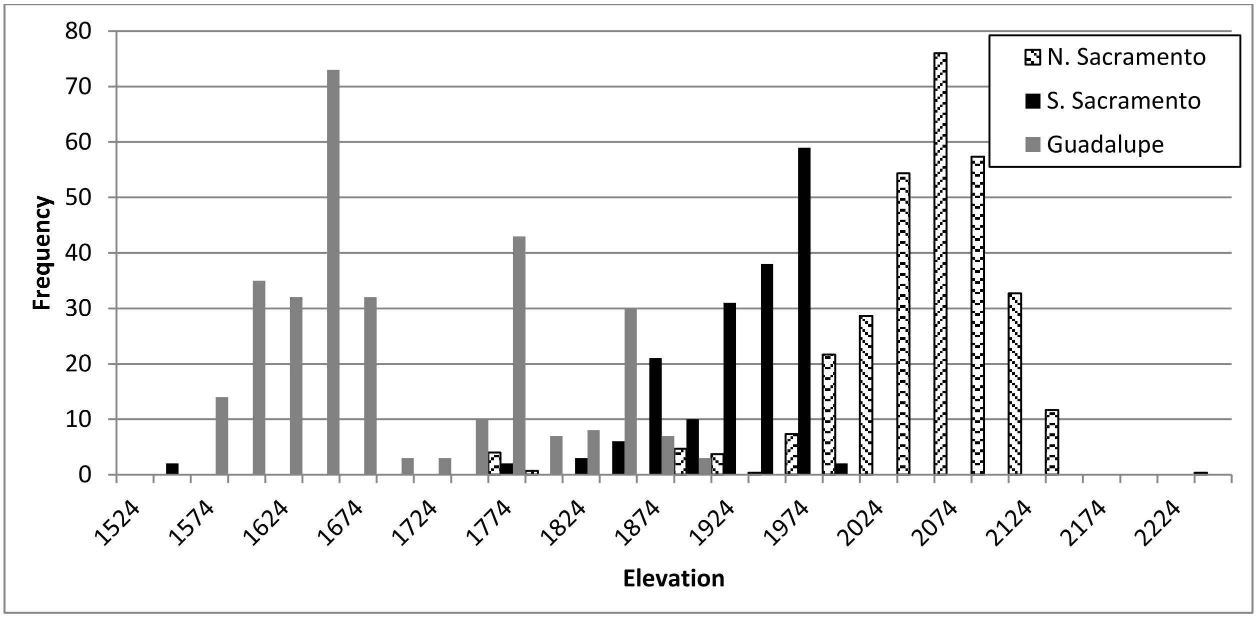

Figure 2. Species occurrence elevation frequency by populations. Northern Sacramento population frequency reduced by factor of 3 for display purposes.

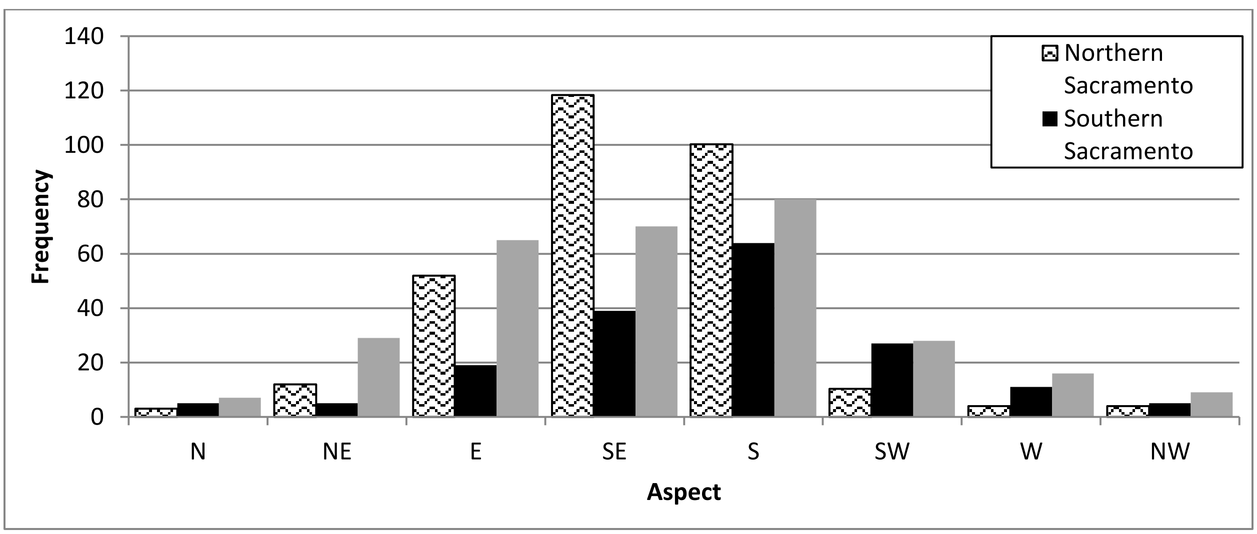

Figure 3. Species occurrence aspect frequency by population.

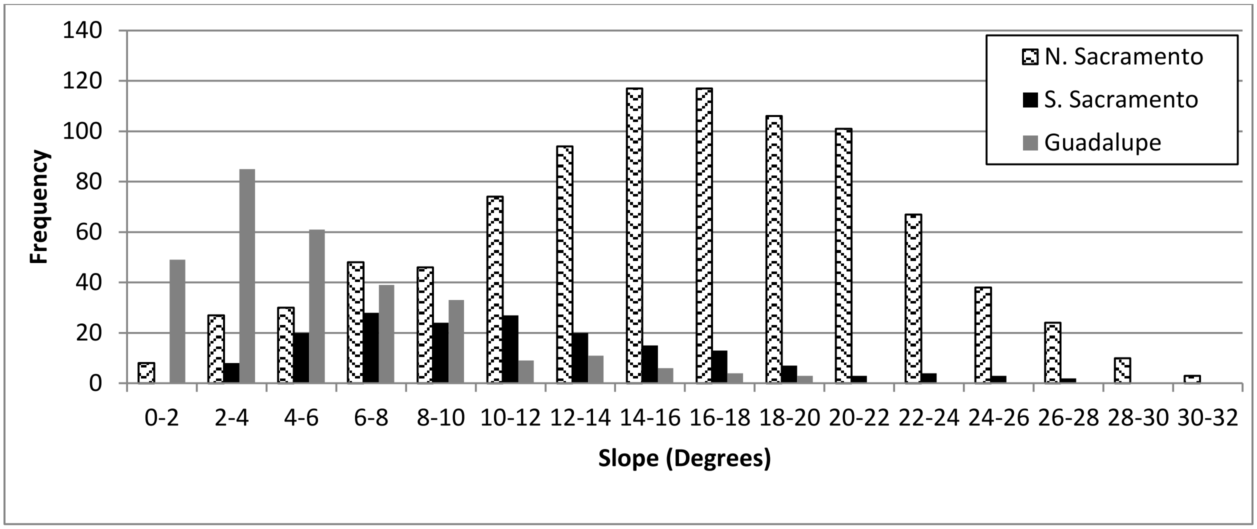

Figure 4. Species occurrence slope degree frequency by population.

The Southern Sacramento population ranges in elevation from 1,524–1,975 meters (m) (5,000–6,479 feet [ft]) (Figure 2). EFK is found on gentle slopes (slope range 2.1–27.5 degrees) with mainly eastern, southeastern, southern, and southwestern exposures (Figures 3 and 4).

The Guadalupe population ranges in elevation from 1,558–1,884 m (5,111–6,181 ft) in a bimodal distribution from 1,558–1,683 and 1,734–1,884 m (5,114–5,521 and 5,689–6,095 ft) (Figure 2). EFK is found on gentle slopes (mean slope range 0.3–10.2 degrees) with mainly northeastern, eastern, southeastern, southern and southwestern exposures (Figures 3 and 4).

II.4.4. Fragmentation

From the available observation data, it appears that the Northern Sacramento population is substantially larger and, to some degree, more clustered. Based on observation data, the Northern Sacramento, Southern Sacramento, and Guadalupe populations had a mean 1-neighbor Element Occurrence (EO) distance (an average distance to the nearest neighbor) of 47.5 m (155 ft), 215 m (705 ft), and 188.8 m (616 ft) respectively. In an effort to better understand this trend, we evaluated each of the model parameters (elevation, slope, and aspect) for each population in terms of their relative proportion to the total available area, which is delineated by the occupied soil map units (the ratio of suitable aspect area: total occupied soils area). Results of this comparison showed no clear relationship between population size and the availability of any one of the suitable abiotic model elements, suggesting that there may be biotic factors not captured by the abiotic model parameters. Such factors may include pollinator range (i.e., the closer a microsite is to another microsite, the higher the probability of pollination and thus effective reproduction) or seed dispersal vectors.

II.4.5 Pollinators

Effective pollination of EFK requires the availability of insect pollinators, in adequate numbers. Diverse flowering plant communities containing plants with overlapping flowering periods may share such generalist pollinators and increase probability of pollination (Ghazoul 2006: 295). This could be of particular importance in smaller EFK populations, where the number of individual cacti is not adequate to attract pollinators.

Optimal or high condition habitat will have diverse floral communities to attract pollinators and no decline in pollinator numbers or species. Declining pollinator abundance could lead to less frequent flower visitation and abrupt or gradual diminution of seed and fruit production in many plants (Cane and Tepedino 2001: 1).

II.5. Geographic range and distribution

EFK is endemic to the northeast side of the Sacramento, and Capitan Mountains in Lincoln County, New Mexico, to middle of the Guadalupe Mountains in Eddy County, New Mexico (Figure 5). Lincoln National Forest and the BLM Pecos District have conducted numerous field surveys for EFK within their jurisdictions.

The number of plants in these survey areas is likely greater not only because survey intensity is less than 100 percent of the potentially occupied habitat, but importantly because non-flowering cacti are difficult to detect and often do not flower at the same time. Population monitoring has not occurred on a routine basis; however, the presence of EFK is usually reaffirmed during subsequent visits, even after intervals of many years, supporting their stable status since the time of listing. An estimate of 11 populations in 4 areas occurs within this range; however, they occur in clusters and the number of individuals within each population is usually not high.

II.5.1. Northern Sacramento

The Northern Sacramento Mountain population center includes the Vera Cruz, and Fort Stanton populations. The Vera Cruz population is located near Nogal, New Mexico on the Lincoln National Forest, Smokey Bear Ranger District. The Vera Cruz population is the northernmost known location of EFK. Nine groups of individual cacti were found on the Vera Cruz Allotment in the Vera Cruz Mountains (U.S. Forest Service [Forest Service] 2012: map). In 2012, during a reconnaissance survey by New Mexico Natural Heritage (NHNM), 56 cacti were documented (NHNM 2017: 11).

The Fort Stanton population, located on the BLM Fort Stanton Snowy River National Conservation Area (NCA), administered by the Roswell Field Office of the Bureau of Land Management (BLM-RFO), supports the largest and most vigorous EFK population. In 2012, 513 cacti were documented there (NHNM 2017: 11).

In the Northern Sacramento Mountain population center, two single observations occur outside of the Vera Cruz and Fort Stanton population locations. One location east of Fort Stanton, was first observed in 1976, and has not been located since. The other location first observed in 2005, is south of the Fort Stanton population near Hightower Mountain, and has not been revisited.

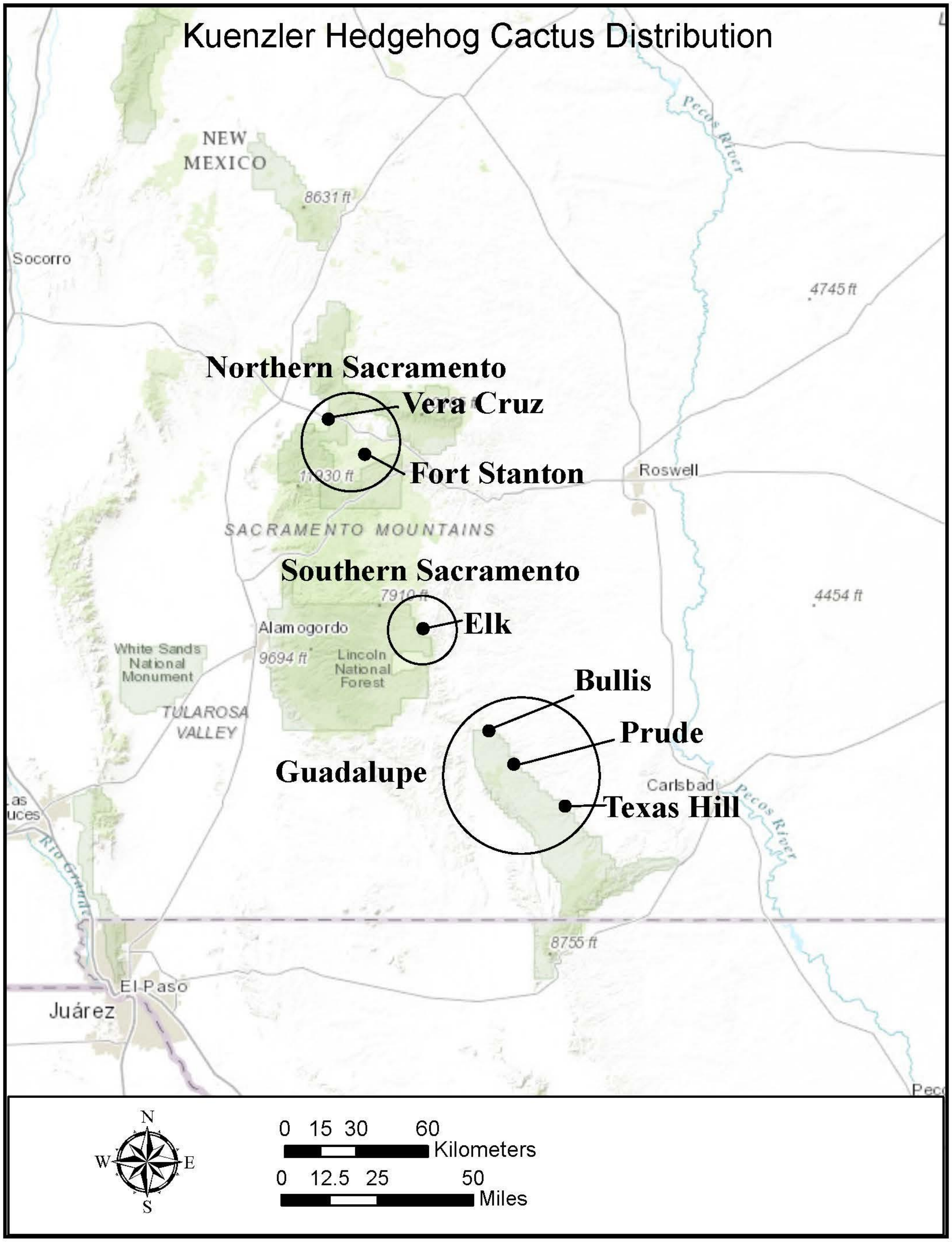

Figure 5. Current distribution of Kuenzler's Hedgehog Cactus.

II.5.2. Southern Sacramento

The type locality for the 1976 description of the Cactus the Southern Sacramento Mountain population center includes the Elk population. The Elk population is located near Mayhill, New Mexico on the Lincoln National Forest, Sacramento Ranger District, land administered by the BLM-RFO, and privately owned. In 2012, 207 cacti were documented (NHNM 2017: 11).

In the Southern Sacramento Mountain population center, three points occur outside of the Elk population location. One location south of the Elk, was first observed in 1980. The other two locations, first observed in 1999, are east of Elk roughly 20 km (12 mi) near Highway 82.

II.5.3. Northern Guadalupe

The Northern Guadalupe Mountain population center includes the Bullis and Prude populations. Bullis and Prude populations are located on the Lincoln National Forest, Sacramento Ranger District, and land administered by the Carlsbad Field Office of the Bureau of Land Management (BLM-CFO). Bullis is the smallest population. In 2012, only two cacti were documented (NHNM 2017: 11). The Prude population had 41 cacti observed.

II.5.4. Southern Guadalupe

The Southern Guadalupe Mountain population center includes the Texas Hill population. The Texas Hill population is located on the Lincoln National Forest, Sacramento Ranger District, and land administered by the BLM-CFO. The Bullis population is the smallest of the species. In 2012, only 78 cacti were documented (NHNM 2017: 11).

II.6. Populations and demographic trends

II.6.1. Populations, sites, colonies, and element occurrences

A population of an organism is a group of individuals within a geographic area that are capable of interbreeding or interacting. Although the term is conceptually simple, it may be difficult to determine the extent of a population of rare or cryptic species, which is certainly the case for the EFK. Surveys on public lands have detected groups of individuals; however since they are difficult to detect outside of flowering season and large areas have not been surveyed, we do not know if these are small, isolated populations or parts of larger interacting populations or colonies.

II.6.2. Documented populations

When the EFK was federally-listed as endangered, in 1979, less than 200 individuals had been found in Lincoln and Eddy Counties, New Mexico (Service 1979: 61,924).

EFK is a small species that is endemic to the northwest side of the Sacramento, and Capitan Mountains in Lincoln County, New Mexico to middle of the Guadalupe Mountains in Eddy

County, New Mexico (Figure 5). It was federally listed as endangered in 1979 (Service 1979: entire). At that time, fewer than 200 individuals had been documented. During inventories from 1976 to 2015, 4,330 individuals were found (NHNM 2017: 5). This number may be imprecise due to potential for undercounting during surveys and double counting individuals in repeated surveys.

II.6.3. Demographic trends

A 2012 reconnaissance survey by NHNM of the 32 highest density sites reported 897 observations (NHNM 2017: 11). The survey results were compared to previous survey efforts and a site trend was determined. Of the 32 surveyed sites 20.5 percent (7) were stable to stable/upward trending (numbers were up by more than 20 percent), 32.3 percent (11) were stable, 31.3 percent (10) were stable/downward to downward trending (numbers were down by more than 20 percent), and remaining 12.5 percent (6) were undetermined (Table 2). Based on this information, the extrapolated trend suggests that greater than half of the populations are stable to increasing. The downward trends were often attributed to recent fire activity.

Table 2. Kuenzler's hedgehog cactus population trends among sites surveyed in 2012. Counts are by year at each sub-population site found among the three major distribution regions: Northern Sacramento Mountains; Southern Sacramento Mountains; and Guadalupe Mountains (Muldavin et al. 2013: 13).

Kuenzler's Hedgehog Cactus Population Trends				
Region	**Population**	**Number of Sub Populations**	**Number in 2012**	**Average Trend 1985–2012**
North Sacramento Mountains	Vera Cruz	1	56	Stable
	Fort Stanton	11	513	Stable/upward
South Sacramento Mountains	Elk	5	207	Stable
Guadalupe Mountains	Bullis	2	2	Upward
	Prude	5	41	Stable/downward
	Texas Hill	8	78	Stable
TOTALS	**6**	**32**	**897**	**~Stable**

II.6.4 Habitat Suitability Model

Our primary purpose for creating a habitat suitability model is to provide a reasonable population estimate. While other uses of the model output are plausible, such applications should be employed with great care. The additive effects of parameter-based error rates, resolution differences, errors and uncertainty in the observation data, as well as unknowns surrounding the ecology of EFK, are key factors that add to overall model uncertainty. In addition, there has been no formal accuracy assessment performed for this model and thus probabilities of detection are generally unknown and should not be inferred. In other words, the spatial model output (suitable habitat polygons) should only be viewed or used as a heuristic guide and not as a definitive binary or probability-based determination of presence or absence; field validation is always warranted and strongly encouraged with any habitat suitability model. See Appendix B for the model description and details.

II.6.5 Population Estimate

The final population estimate was obtained by multiplying the modeled area of suitable habitat (above) by an estimated density value (see Appendix B for methods). The estimated mean density values (plants per acre) by population:

Northern Sacramento	0.77 plants per acre
Southern Sacramento	0.31 plants per acre
Guadalupe	0.12 plants per acre

Using these density values, the final population estimates are:

Northern Sacramento	8,025 plants
Southern Sacramento	4,617 plants
Guadalupe	8,007 plants
Total	20,649 (or ≈ 20,000)

We consider this a fairly conservative estimate for the following reasons: 1) the model is limited to the watershed where known observations occurred; 2) the parameter data (elevation, aspect, and slope) was limited to omit outliers and thus reduce the total area delineated; 3) the final model was clipped 40.6 cm (16 in) annual precipitation isopleth (NMEMNRD1989: 91; PRISM 2017: 4) we used only 2012 observation data in our density estimates; and 5) our characterization (grouping) of plant densities was an intermediate value.

Recent survey results (BLM 2017: entire) were used to ground-truth the model. These data were used to re-estimate the Northern Sacramento population density as 0.15 plants per acre. This results in a Northern Sacramento population estimate of 1,534 plants for a total population of 14,158 (or ≈ 14,000). In an effort to be even more conservative in the population estimate, we used the lowest calculated population density value of 0.12 plants per acres for the Southern Sacramento population as well. This results in a Southern Sacramento population estimate of 1,765. We therefore estimate a total EFK population of 11,000–20,000 plants.

III. Summary of Individual, Population, and Species Requirements

III.1. Requirements of Individuals

III.1.1. Habitat

Typical EFK habitat is the lower fringes of the pinyon-juniper woodland from about 1,560 to 2,130 m (5,100 to 6,990 ft) elevation. Occupied habitat consists of flat to gentle slopes (mean slope range 0 to 50 degrees) or benches with gravelly to rocky soils and southern, eastern, and western exposures. Soils may be derived from limestone or intrusive rocks of the Sacramento or Capitan uplifts. EFK also occurs on unconsolidated, gravel hills in the Fort Stanton area (BEEC 2002: 27).

EFK distribution does not appear to be random, but restricted to discontinuous microsites. Distribution within the occupied microsites is clumped. Section II.4.4 suggests that biotic factors such as the proximity of a microsite is to another microsite may increase the probability of pollination and thus effective reproduction or seed dispersal vectors.

III.1.2. Reproduction

EFK begin reproducing when they reach 4 to 5 years of age (Sivinski 2007: 96). Most 4-year-old plants exceeded 4.0 cm (1.6 in) in diameter (NMEMNRD1989: 107). Budding occurs in April and flowering normally occurs during the latter half of May into early June. Warm years can initiate earlier flowering and cool springs may delay flowering until early June (BEEC 2002: 27). Flowers are large for the size of the plant, up to 10 cm (4 in) long. Fruits form in August and are bright red when mature, ovoid to cylindrical, may be over 5 cm (2 in) long, and are spiny with miniature versions of the stem spines. Each plant may have three to six fruits, each fruit having an average of 1,050 seeds (NMEMNRD1989: 106). Seeds are black and pitted. Seed dispersal occurs during September and October by rodents, wind, and water (BEEC 2002: 27).

The slow growth rate, long time required to reach reproductive maturity, and high mortality rate (discussed below) are factors that limit reproduction of EFK. Out-crossing requires genetically diverse cactus populations within the foraging range of pollinators, and is less likely to occur in small, isolated populations. Insufficient pollinator populations may limit successful fertilization; hence, native pollinator conservation is essential for successful reproduction of this species. Healthy pollinator populations, in turn, require intact, diverse, native plant communities. Bees, the assumed natural EFK pollinators, are relatively small, so we expect their foraging ranges to be fairly limited. Therefore, the health and diversity of native vegetation within the vicinity of cactus populations may be particularly important for successful reproduction; for these purposes we suggest that a range of 50 to 500 m (164 to 1,640 ft) is of greatest importance.

III.1.3. Lifespan and mortality rates

The EFK lifespan is potentially decades long. Brack (2017: entire) observed individuals that had lived up to 40 years in a greenhouse setting. Based on observed growth rates, individuals become reproductive at about 4 to 5 years of age, and large individuals may be at least 40 years old. However, the annual mortality rate of established individuals is 10 percent. This number is about equally offset by germination and development of new seedlings. On an average year a stasis is reached between mortality and reproduction (NMEMNRD 1989: 107).

III.2. Requirements of Populations

III.2.1. Stable or increasing demographic trends

Population persistence depends on stable or increasing demographic trends: Recruitment of new individuals must equal or exceed mortality. Recruitment requires successful reproduction (described above). NHNM (2017: 11) reviewed 32 EO's of which 56 percent (18) were stable to stable/upward trending (numbers were up by more than 20 percent), 31 percent (10) were stable/downward to downward trending (numbers were down by more than 20 percent), and remaining 13 percent (6) were undetermined. The downward trends were often attributed to recent fire activity.

EFK population dynamics can be influenced by the periodic infestations of the parasitic insects. Observations have noted apparent direct impacts on individuals resulting from the coreid bug *Chelinidea vittiger* (Alexander 2017a: 1). These insects increase the probability of the introduction of pathogenic bacteria and fungi. Damage associated with these insects is known to induce floral abortions in cactus (Miller et al. 2008: 145). Alexander (2017a: 1) also suggested that coreid bug damage may be interfering with flower development, noting that 26 cacti showed signs of failed flower development. Assuming these are not newly-introduced species, EFK has been coevolving with them and is able to persist. The determination of demographic trends is more realistically based on meta-populations at a landscape geographical scale, rather than individual colonies. Within such landscapes, at any given time only a small fraction of the suitable habitat (microsites) supports living colonies, and the distances between colonies is a protection against parasite infestations.

III.2.2. Genetic diversity

The degree of genetic diversity within EFK populations is important for several reasons. First, diversity within and among populations should confer populations, and the subspecies, greater resistance to pathogens and parasites, and greater adaptability to environmental stochasticity (random variations, such as annual rainfall and temperature patterns) and climate changes. Second, low genetic diversity within interbreeding populations leads to a higher incidence of inbreeding, and potentially to inbreeding depression. Finally, based on greenhouse studies, the EFK breeding system is believed to be primarily through out-crossing (Brack 2017: entire).

III.2.3. Distribution of suitable habitat patches

The distance between colonies has two opposing effects on their persistence. Greater distance reduces susceptibility to parasite infestation (discussed above), but also reduces the amount of gene flow, by means of pollinators vectoring pollen, or through seed dispersal, between colonies. Thus, the persistence of entire populations would require fairly large landscapes where discontinuous suitable habitat (microsites) are distributed and populated at a density low enough to hold the parasites at bay, but high enough for bees and other pollinators and seed dispersers to vector genes between them.

III.3. Species Requirements

The viability of a species can be assessed in terms of its resilience, redundancy, and representation (Shaffer and Stein 2000: 307–310). Resilience refers to population sizes; larger populations are more likely to endure than small ones. Redundant populations increase the species' chances of surviving catastrophic events. Representation refers to the breadth of genetic diversity necessary to conserve long-term adaptive capability. The best available information does not indicate what the minimum viable degree of representation and redundancy should be; it is reasonable to conclude that more is better.

IV. Factors Affecting the Survival of Kuenzler's Hedgehog Cactus: Threats, Vulnerabilities, and Conservation Challenges

The following describes factors that affect, either positively or negatively, the continued survival of EFK.

IV.1.1. Land Management

Habitat destruction by road construction and home building has affected a very small part of the areas occupied by EFK cactus. At the present time, there are no significant mining or oil and gas production activities within the habitat of this cactus. Most of the known occupied habitats occur in relatively remote areas, which are unlikely to be converted to land uses other than open range for livestock grazing (Service 2005: 12). A significant portion of EFK modeled suitable habitat is managed by Forest Service and BLM for multiple uses (i.e., recreation and livestock grazing)(Table 3).

Table 3. Land Management/Ownership of modeled suitable habitat.

Management	Acres	Percent of Ownership
Forest Service	41,886	44.4
BLM	23,764	25.2
Private	20,469	21.7
State	6,991	7.4
NPS	1,198	1.3
Tribal	3	0.0
DOD	1	0.0
Total	**94,312**	**100**

Long-term conservation of EFK is achieved through protections and management on Federal lands. However, the ESA does not prohibit or control the take of EFK on private, tribal, or State lands unless the taking is a consequence of an activity that spends Federal funds, requires a Federal permit, or is in violation of State law, or is for commercial, interstate sale. The New Mexico threatened and endangered plant regulations also do not protect EFK or its habitats on private lands, with the exception of plant collection not authorized by the landowner.

Government agencies and conservation organizations collaborate and contribute resources to conserve EFK and its habitat. Development and management projects are evaluated and modified, if necessary, to avoid detriment to EFK and its habitat. Threat due to changing land management is considered low.

IV.1.2. Fire

EFK probably does not require fire for germination, or establishment. However, periodic fire is likely to be necessary for population persistence to reduce juniper encroachment into suitable habitat and reduce fuel loads. Wilkinson (1997: 83), and Brown et al. (2001: 121), reported that the Sacramento Mountains, pinyon-juniper stands had a historical fire interval of 25–30 years. This fire interval maintained savanna-like conditions in moderate to high productivity pinyon-juniper woodlands by thinning young non-fire resistant trees, before the introduction of grazing and fire suppression.

The diverse shrub and forb vegetation that sustains healthy pollinator pollinations is maintained by periodic wildfire; without fire, dense juniper groves frequently displace these shrubs and forbs. Hence, if the native plant diversity of entire landscapes surrounding EFK populations succumbs to juniper encroachment, pollinator populations will likely decline, and reproduction and gene flow between its colonies may be reduced.

Sivinski (2007: 93) found that wildfire can cause high mortality in EFK, and that EFK was slow to recover. This led to studying the effect of prescribed burns as a means of reducing wildfire risk. Wester and Britton (2007: 11) found no evidence that the species was negatively affected by prescribed fire. However, impacts are relative to adjacent high fuel loads and the resulting heat intensity during fire events did increase mortality. Fuel reduction projects and vegetation treatments have been proven as a means of mitigating wildfire hazards, to lessen catastrophic fire. This suggests that prescribed burns or mechanical fuel reduction in EFK habitat could be designed to remove fuel loads without causing direct mortality associated with wildfire (May 2006: 44).

Livestock grazing has had a significant effect on the frequency of natural fire within EFK habitats. Removal of fine fuels by grazing animals reduces the ability of a fire to start and carry through the landscape. Land managers have in the past followed an aggressive wildfire suppression program. The result is a disruption of the natural fire regime and an increase of woody vegetation in grassland and savanna habitats. Land managers presently see the need to reintroduce fire into these habitats for the purpose of restoring grasslands and increasing forage for livestock production (Service 2017: 1,682).

We believe that uncontrolled wildfire to be a significant threat to EFK. Wildfire is capable of devastating or potentially eliminating small populations of EFK. However, prescribed fire or mechanical fuel reduction used to manage fuel loads would be important to reduce the risk of catastrophic wildfire. Therefore, wildfire is considered a moderate threat to EFK.

IV.1.3. Livestock grazing

The Recovery Plan lists grazing as a significant threat (Service 1985: 8). A 2-year study (1984-1985) by The Nature Conservancy found that during a year of cattle grazing with 65 percent forage utilization, 21 out of 172 individual cacti were found dead outside the fenced exclosure while there was zero mortality inside the exclosure where no grazing had occurred (Bates 1985: 2). One cause of mortality to individuals is trampling by livestock. Concentrating livestock by placing feed, salt, or watering points near cactus clusters can increase the likelihood of cactus being trampled. Livestock grazing also removes grass cover, which can reduce the suitability of sites for seed germination and seedling establishment and can expose adult plants (Service 1985: 10; Service 2005: 12).

Chauvin et al. (1998: 4) found that mean grass cover on EFK sites (53 percent) was significantly greater than at sites without EFK (29 percent). Litter cover was significantly higher, and rock and gravel cover significantly lower, on EFK sites.

DeBruin (1996: 7) found a significant positive relationship between condition of juvenile EFK and cover of basal vegetation, and grass cover and EFK condition. A mean of 24 percent ground cover surrounded healthy EFK, with the amount of plant biomass surrounding individual cacti positively correlated to the cactus's condition (Debruin 1996: 8).

Chauvin et al. (2001: 3) found similar findings in the Guadalupe Mountains. EFK was detected most often on moderately grazed sites shaded by native grasses.

A total of 126 grazing allotments on BLM and Forest Service managed lands cover roughly 80 percent of the total modeled suitable habitat (Section II.6.5). Over 50 percent of all EFK observations occur on 10 livestock grazing allotments (Table 4).

Table 4. Top ten grazing allotments with suitable habitat and largest number of total EFK observations over time.

Management	Allotment Name	Suitable Habitat (acres)	Active /Inactive	Number of Cacti
BLM	Ft Stanton NCA	3,316	Inactive	2,396
Forest Service	Mule Canyon	858	Active	313
Forest Service	National	22,244	Active	270
Forest Service	Vera Cruz	3	Active	252
Forest Service	Eagle Creek	14	Active	227
BLM	Texas Hill	5,616	Active	183
Forest Service	Prude	1,578	Active	177
Forest Service	Sargent	942	Active	77
BLM	Upper Segrest Draw	2,220	Active	55
BLM	Red Lake	Not in Model	Active	16
TOTAL		**36,790**		**2,224**

The Northern Sacramento population and location of the largest EFK numbers, the Fort Stanton National Conservation Area (NCA) has not been grazed since the early 1990's and it is not being considered for grazing (BLM 2002: 9; BLM 2013: 20).

The direct or indirect impacts due to grazing, such as trampling, and removal of vegetative cover are minor due to effective grazing management by land management agencies that allows the plant to persist in active allotments. We believe conservative livestock grazing managed responsibly can be used as a management tool to help reduce fuel loads and reduce the risk of wildfire. Therefore, the threats associated with livestock grazing are considered low.

IV.1.4. Illicit collection

Many rare cactus populations have been depleted by collectors. The Recovery Plan lists illegal collection as a threat to the species (Service 1985: 9). Evidence of illegal collection has been observed recently (Baggao 2017: 1). Although illicit collection has not significantly impacted the species, the wild populations openly accessed by the public remain vulnerable.

In small populations, removal of individuals could have detrimental impacts to the small populations, and even more so on individual colonies due to reduced genetic diversity, and limited mature individuals for reproduction. Illicit collection is considered a moderate threat to EFK.

IV.1.5. Parasitic Insects

Observations have noted apparent direct impacts on individual EFK cacti resulting from the coreid bug (*Chelinidea vittiger*) (Alexander 2017a: 1). These insects increase the probability of the introduction of pathogenic bacteria and fungi. Damage associated with these insects are known to induce floral abortions in cactus (Miller et al. 2008: 145). Alexander (2017a: 1) also suggested that coreid bug damage may be interfering with flower development, noting that 26 EFK showed signs of failed flower development. Periodic outbreaks of insect parasitism seems to occur when cactus populations become very dense (DeBruin 1996: 8).

In large, dense populations of EFK the threat of parasitic insects is high. In the less dense, smaller populations the risk is lower. Parasitic insect infestation in any EFK population has the ability to significantly reduce reproduction, and reduce population numbers. Therefore, the threat parasitic insect's pose to EFK is considered moderate.

IV.1.6. Herbivory

Rodents can act as both predators and dispersers of seeds. Rodent herbivory damage has been observed and is known to increase mortality in EFK (Forest Service 1989a: 4; Forest Service 1989b: 20; Marron and Associates 2004: 3–4). However, seed dispersal can be facilitated by rodents (BEEC 2002: 27). The threat of herbivory is considered low.

IV.1.7. Pollinators

EFK is assumed to be visited by generalist pollinators. It is difficult to predict that pollinators of the cactus will decline over time. There is a lack of information on decline of insect pollinators in general in the southwest, including information specific to EFK. We do not have the available information needed to draw any conclusions or make predictions about probable effects to the resiliency of EFK in the foreseeable future.

IV.1.8. Small population size and density

Small populations are less able to recover from losses caused by random environmental changes (Shaffer and Stein 2000: 308–310), such as fluctuations in recruitment (demographic stochasticity), variations in rainfall (environmental stochasticity), or changes in the frequency of wildfires. EFK has an out-crossing breeding system. The probability of successful fertilization between unrelated individuals is reduced in small, isolated populations. The remaining plants would produce fewer viable seeds, further reducing population recruitment and engendering a downward spiral toward extirpation. The demographic consequences of small population size are compounded by genetic consequences, since reduced out-crossing corresponds to increased inbreeding. In addition to population size, it is likely that population density also influences population viability; density must be high enough for gene flow within meta-populations, but low enough to minimize parasite infestations.

Small, reproductively isolated populations are susceptible to the loss of genetic diversity, to genetic drift, and to inbreeding. The loss of genetic diversity may reduce the ability of a species or population to resist pathogens and parasites, to adapt to changing environmental conditions, or to colonize new habitat. Conversely, populations that pass through a "genetic bottleneck" may subsequently benefit through the elimination of harmful alleles. Nevertheless, the net result of loss of the genetic diversity is likely to be a loss of fitness and lower chance of survival of populations and of the taxon.

Genetic drift is a change in the frequencies of alleles in a population over time. Genetic drift can arise from random differences in founder populations and the random loss of rare alleles in small isolated populations. Genetic drift may have a neutral effect on fitness, but is also a cause of the loss of genetic diversity in small populations. Genetic drift may also result in the adaptation of an isolated population to the climates and soils of specific sites, leading to the development of distinct ecotypes and to speciation.

Because small populations are more susceptible to stochastic events, and loss of genetic diversity reduces EFK's ability to adapt to environmental changes, the threats associated with small population size is moderate.

IV.1.9. Climate change

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2013: 23) projects the following changes by the end of the 21st century, relative to the 1986 to 2005 averages: It is virtually certain that most land areas will experience warmer and fewer cold days and nights; it is virtually certain that most land areas will experience warmer and/or more frequent hot days and nights; it is very likely that the frequency and duration of warm spells and heat waves will increase in most land areas; it is very likely that the frequency, intensity, and/or amount of heavy precipitation will increase in mid-latitude land masses; it is likely that the intensity and/or duration of droughts will increase on a regional to global scale. The magnitude of projected changes varies widely, depending on which scenario of future greenhouse gas emissions is used.

This global climate information has been downscaled to our region of interest, and projected into the future under two different scenarios of possible emissions of greenhouse gases (Alder and Hostetler 2017: 2). Climate predictions for the cactus area include a 5 to 6 percent increase in maximum temperature (up to 4 ºC [7.2 ºF]), 11 percent decrease in precipitation, and a 25 percent increase in evaporative deficit over the next 25 years (National Climate Change Viewer, Four County Data, http://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp, accessed May 15, 2017).

In 11 of the last 15 years (2001–2015) there has been moderate to exceptional drought conditions in the cactus area with 10 percent of the time in exceptional drought (National Drought Mitigation Center 2015, Four County Data). The 2002–2003 drought spanned all of the southwestern North America was anomalously dry with unusually high temperatures (Breshears et al. 2005: 15,144) similar conditions occurred in 2011–2013.

Climate change also involves an increase in atmospheric carbon dioxide which is commonly associated with increased temperatures and the greenhouse effect. This increased carbon dioxide directly affects plant photosynthesis (Huxman and Scott 2007: 28). At the plant level, adapting to drought involves the ability to balance carbon sequestration (the uptake and storage of carbon), carbon respiration (efflux back into the atmosphere), and maintain sustainable evapotranspiration rates (Huxman and Scott 2007: 28). Adaptation would also require a plant to change its phenology (timing of life cycle events) to coincide successfully with extreme shifts in temperature, precipitation, and soil moisture (Walther et al. 2002: 389) which are all part of the evapotranspiration equation. The potential for rapid climate change, which is predicted for the future, could pose significant challenges for plants because they may not be able to adjust their phenology or photosynthetic mechanisms quickly enough.

Cacti have a unique photosynthetic pathway referred to as Crassulacean acid metabolism (CAM) which is most effective in low soil moisture, intense sunlight, and high daytime temperature conditions, and is considered to be a desert adaptation (Nefzaoui et al. 2014: 121). CAM plants may have an advantage under drier conditions predicted by climate change (Reyes-Garcia and Andrade 2009: 755). If atypical cactus mortality occurs, this could be evidence that a climatic severity threshold may have been crossed even for this well-adapted CAM species.

Growing seasons are becoming longer and warmer in many regions (Kunkel 2016: 1) including the Southwest (Cayan et al. 2001: 399; Easterling 2002: 1,329). Earlier soil moisture stress would result in decreased flowering and reproduction, and because this cactus has a limited distribution, we would predict a substantial population reduction with a long-term warming trend. Munson et al. (2013: 2,030) predicts declines in vegetative cover including cacti in Chihuahuan Desert habitats due to climate change. Based on a limited distribution dataset Still et al. (2015: 114) ranked EFK as extremely vulnerable to climate change.

EFK has experienced rebounds from periods of drought in the past. However, should substantial climate change materialize with increased severity and frequency of drought, it would likely reduce the long-term survivorship of this species. However, without sufficient monitoring in place to assess trends, the severity of this threat can only be surmised based on other cacti and drought research. Therefore, the threat of climate change may result in impacts on EFK and habitat. We believe the threat of climate change is moderate.

V. Conservation Efforts

V.1. Recovery Plan

The Recovery Plan while dated has multiple objectives to protect and maintain the species that are useful today (Service 1985: entire). There is only one downlisting criterion: to secure and maintain a wild population of 5,000 individuals for a period of 5 years (Service 1985: 13). This criterion was expected to be met by establishing more than one self-sustaining population and removing collecting pressure by artificial propagation and law enforcement (Service 1985: 13). Major steps to recovery included: 1) develop and implement habitat management plan(s), 2) protect habitat on private lands, and 3) monitor populations.

Based on observations and the population estimate (11,000–20,000 individuals), we believe that the population target has been exceeded and population levels have been secure over the last 5 years. Two additional populations have been identified through further survey effort. Collecting of wild specimens while not absent is very low in occurrence, and at least two businesses have artificially propagated specimens for sale.

We still need to develop habitat management plans with each of the major Federal land managers, Forest Service and BLM, which would include survey of suitable habitat for EFK if ground disturbing activities are expected. In addition, a comprehensive plan covering all three populations is needed to monitor the status of each population and provide input for management decisions. The monitoring plan would include evaluation of illegal collection frequency and more recently identified threats such as habitat fragmentation and lack of pollinator success.

Important habitat on private lands should be identified and landowners approached for willingness to survey and enlist in conservation agreements where appropriate. Finally a revised recovery plan should be developed with both downlisting and delisting criteria and objectives. Downlisting does not affect our ability to implement these conservation measures.

V.2. Section 7 Consultation

One formal consultation has been completed under section 7 of the Endangered Species Act (ESA) that have led to actions that address managing existing habitat on public lands listed in the recovery plan; Prescribed burns and their effects on the EFK (22420-2003-F-0078). Seven informal consultations have been completed involving EFK, including grazing permit renewal (02ENNM00-2013-I-0064), power line repair (02ENNM00-2014-I-0265), prescribed fire (02ENNM00-2017-I-0290), prescribed fire (22420-2003-I-0145), grazing permit renewal (22420-2007-I-0098), chemical treatment of invasive woody plants (22420-2009-I-0006), and mechanical treatment of invasive woody plants (22420-2010-I-0011).

V.3. Section 6-Funded Grants

ESA section 6 provides grants to States and territories to participate in a wide array of voluntary conservation projects for candidate, proposed, and listed species. The program provides funding to States and territories for species and habitat conservation actions on non-Federal lands (Service 2009: entire). The Service has awarded one section 6 grant to gather the baseline data on distribution, population size, species biology, ecology, population structure and demography of the federally listed threatened or endangered plant species in New Mexico (NMEMNRD 1989: 1).

VI. Current Status

There have been 4,330 EFK documented at 315 sites throughout EFK's range from 1976–2015 (NHNM 2017: 5). A complete census of all known locations has not been performed to date. In 2012, NHNM conducted a reconnaissance survey of the 32 highest density sites (NHNM 2017: 11). Of the 32 surveyed sites 20 percent of the sites increased by more than 20 percent, 32 percent were stable, 31 percent decreased by more than 20 percent (Table 2). Based on this information, the extrapolated trends suggest that greater than half of the populations are stable to increasing.

We developed a potential habitat model based on the soil types, elevation, slope, aspect, and average annual rainfall of documented populations (See Appendix B). This model predicts that 38,136 ha (94,238 acres) of potential habitat occur in the currently-known range. Based on this model and density calculations from nearby populations we estimate that the range-wide population is 11,000–20,000 plants.

VII. Assessment of Viability

For EFK to maintain viability, its populations or some portion thereof must be resilient. Stochastic events that have the potential to affect EFK populations include drought and climate change. Factors that influence the resiliency of populations include habitat, abundance of insect pollinators, and rainfall. Additionally, secondary factors include agents of seed dispersal (wind, water, mammals, and birds), and temperature for seed germination. Influencing those factors are elements of EFK habitat that determine whether EFK populations can grow to maximize habitat occupancy, thereby increasing the resiliency of populations.

Habitat Quantity – The most important factors that have the potential to limit EFK populations is the availability and quantity of suitable habitat. There is insufficient data to determine values for optimal density, and optimal abundance in order to calculate how much habitat EFK requires. Therefore, using the estimated potential suitable habitat values (see II.6.5 Habitat Suitability Model, Appendix 2) and our best professional judgement, we consider a population area greater than 8,000 ha (20,000 acres) to be high (good) condition for these population complexes, from 4,000 – 8,000 ha (10,000 to 20,000 acres) to be moderate condition, and less than 4,000 ha (10,000 acres) to be low (poor) condition.

Abundance – In order to have a stable, ongoing population, it is necessary to have at least a certain number of plants at all life stages in that population, including seeds in a seed bank, seedlings, and mature plants. We are using the number of plants as the overall indicator of abundance for EFK populations. Without a Population Viability Analysis (PVA) to indicate what an optimal abundance level should be, using our best professional judgement, we consider a population with over 500 mature plants to be in high condition. The largest current population extant (Fort Stanton) has a population size of 513 plants, and has persisted at about this level; thus, we consider this to be an optimal population size. The Southern Sacramento population has a population size of 206 plants, and has persisted at about this level; thus we consider a moderate condition would be between 200 and 500 plants. We consider a population under 200 to be a low (poor) condition because of negative impacts on reproduction and connectivity.

Reproduction – For plants such as EFK, reproductive success dictates that mature plants must produce a large number of viable seeds, and that these seed have the right conditions for germination, and that seedlings have the necessary habitat elements to allow them to grow and mature into the successive life stages. If there is an increasing trend it would follow that mature plants are setting and producing an abundant number of seeds, that there is an adequate, viable seed bank, that conditions exist such that germination is effective, and that the habitat needs of the juveniles are being provided. Reproduction with an optimal condition would be demonstrated in an increasing trend. A moderate condition would have stable trend. A declining trend would demonstrate a poor reproduction condition.

An optimal production of juveniles may temporarily deplete the seed bank, but with the large amount of seeds produced by mature plants, it is likely that any periodic depletion of seed back will be short term and replenished.

Habitat Elements that Influence Resiliency

Connectivity – Connectivity is necessary for EFK reproduction. The degree of connectivity is related to the efficiency of pollinators, probability of fertilization, and genetic diversity. Habitat with optimal conditions should include numerous colonies within an average distance to the nearest neighbor of less than 50 m (164 ft). Habitat with moderate conditions should include colonies within an average distance to the nearest neighbor between 50 to 200 m (164 to 656 ft). Habitat with low (poor) conditions should include colonies within an average distance to the nearest neighbor greater than 200 m (656 ft).

However, large population numbers with high connectivity would be more susceptible to insect infestation and damage. As discussed in section IV.1.5, parasitic insects can cause floral abortions, negatively impacting reproduction and seed bank.

Species Representation

Maintaining representation in the form of genetic or ecological diversity is important to maintain EFK's capacity to adapt to future environmental changes. An abundance of insect pollinators, particularly bees, leads to genetic diversity by the process of cross pollination between patches within a population. The differences in habitat conditions and geographic range result in genetic differences between the populations of EFK, which may be expressed morphologically. There is a need to maintain the genetic differences between populations as their potential genetic and life history attributes may buffer the species to adapt to environmental changes over time. EFK has likely lost genetic diversity as the sizes of populations have been reduced, and maintaining the remaining genetic diversity may be important to the capacity of EFK to adapt to future environmental change.

Species Redundancy

EFK needs to have multiple resilient populations distributed throughout its range to provide for redundancy. The more populations, and the wider the distribution of those populations, the more redundancy the species will exhibit. Redundancy reduces the risk that a large portion of the species' range will be negatively affected by a catastrophic natural or anthropogenic event at a given point in time. Species that are well-distributed across their historical range are considered less susceptible to extinction and more likely to be viable than species confined to a small portion of their range (Carroll et al. 2010: entire; Redford et al. 2011: entire). All EFK populations are fairly isolated from one another, and it is unknown if any gene flow occurs among the three populations, unless it were augmented for conservation with human assistance.

Methodology

To summarize the overall current resiliency of EFK populations, we ranked each of the population factors and habitat elements discussed above into three condition categories (high, moderate, and low) based on the four population factors and habitat elements discussed above (see section VII). The current condition category is a qualitative assessment of the likelihood of persistence based on the analysis of the three population factors and one habitat element.

We gave a numerical value to the population factors of 3 to each high (good) condition, 2 to each moderate condition, 1 to each low (poor) condition. Because connectivity (habitat element) has wide-reaching influences to the population factors, we believe that connectivity holds a greater value to viability. Therefore, we gave a numerical value to the habitat element (connectivity) 10 to each high (good) condition, 5 to each moderate condition, and 1 to each low (poor) condition. We then did a simple averaging of the four factors to arrive at the overall condition of each of the populations. The Northern Sacramento population has the most robust cacti numbers with a stable trend, and greatest connectivity, we consider this population to be an overall high (good) condition population. Since we do not have a PVA, we used the Northern Sacramento population as a benchmark for overall condition, and we considered an average score of 3 or greater to be high (good) overall condition, 1.6–2.9 to be moderate overall, 1.5 or less to be low (poor) overall condition. Table 5 defines the rankings for each habitat and population element. Table 5 defines the rankings for each habitat and population element.

Next, we considered how the overall condition of a population would translate into likelihood of persistence over approximately 50 years. For a population in high (good) overall condition, we estimate that the probability of persistence over the next 50 years would be 90 percent or higher (in other words a 10 percent or less probability of extirpation. For a population in moderate condition, we estimate that the probability of persistence over approximately the next 50 years would be 66 to 90 percent (10 to 33 percent probability of extirpation), and for one in low (poor) condition, a probability of persistence of 0 to 66 percent over 50 years (33 to 100 percent chance of extirpation. This is summarized in Table 6 below.

Table 5. Population and habitat characteristics used to create condition categories.

	Population Factors			Habitat Elements
Condition Category	**Habitat Quantity**	**Abundance**	**Reproduction**	**Connectivity**
High (good)	>20,000 acres	>500	Upward	<50 m
Moderate	10,000-20,000 acres	500 to 200	Stable	50 to 200 m
Low (poor)	<10,000 acres	<200	Downward	>200 m

Table 6. Presumed probability of persistence of current condition categories.

Likelihood of Persistence:	**High**	**Moderate**	**Low**
Range of Presumed Probability of Persistence over ~50 years	**90–100%**	**66–90%**	**0–66%**
Range of Presumed Probability of Extirpation over ~50 years	**0–10%**	**10–33%**	**33–100%**

Table 7. Current resiliency of EFK populations. Population factor rankings are based on the most recent trend surveys by NHNM (2017)(see Table 2). Habitat element rankings (connectivity) are based on population connectivity descriptions in section II 4.4.

				Population Factors			Habitat Elements	
Region	**Population**	**Estimated Potential Habitat (acres)[1]**	**Number of Cacti[2]**	**Habitat Quantity**	**Abundance**	**Reproduction[2]**	**Connectivity**	**Overall Condition with Continuing Conditions**
Northern Sacramento	Vera Cruz	10,468	**56**	Moderate	Low	Moderate	High	High
	Fort Stanton		**513**		High	High		
Southern Sacramento	Elk	14,715	**207**	Moderate	Moderate	Moderate	Moderate	Moderate
Guadalupe	Bullis	69,055	**2**	High	Low	High	Low	Moderate
	Prude		**5**		Low	Low		
	Texas Hill		**8**		Low	Moderate		

[1]Based on model (Appendix B)
[2]Based on NHNM (2016)

VII.1. Current Viability

VII.1.1. Resilience and Redundancy

Resilience refers to the population size necessary to endure stochastic environmental variation (Shaffer and Stein 2000: 308–310). Redundancy refers to the number and geographic distribution of populations or sites necessary to endure catastrophic events (Shaffer and Stein 2000: 308–310).

EFK distribution and abundance have been variable over time. Currently, surveyed areas appear to be stable. The primary cause of the declines in habitat quantity and population numbers is stochastic events including wildfire and prolonged drought. Both the larger and smaller populations face stressors from these stochastic events. These stressors, alone or in combination, could result in the further decline of one or more of the three populations, further reducing the overall redundancy and representation of the species.

Northern Sacramento – This population has the highest number of plants and highest density, mostly occurring on BLM and Forest Service managed lands; however they continue to be threatened by wildfire which increases mortality, insect damage reducing reproduction, and climate change. The removal of livestock grazing from a significant portion of this population habitat has increased the level of fine fuels, which increases the risk of catastrophic uncontrolled wildfire. It is projected that climate change may result in increased periods of drought, increased average temperatures, decreased annual rainfall, and milder winters; however EFK has demonstrated adaptability to variations in environmental conditions. Large numbers, plus high connectivity and density in this population, increases the risk of insect infestation. Assuming the parasitic insects are not newly-introduced species, EFK has been coevolving with them and is able to persist. This population appears to have sufficient floral resources, pollinator availability, and high connectivity between colonies. Therefore, we predict that over time, conditions will likely continue supporting a robust and stable population with a complex of dense colonies, able to withstand stochastic events.

Southern Sacramento population – This population represents roughly a quarter of the current EFK numbers and is currently stable. It continues to be threatened by a moderate risk of wildfire, insect damage, and climate change. It is projected that climate change may result increased periods of drought, increased average temperatures, decreased annual rainfall, and milder winters; however EFK has demonstrated adaptability to variations in environmental conditions. This moderately sized population appears to have moderate floral resources, moderate pollinator efficiency, and moderate connectivity between patches. We predict that over time, overall conditions will likely remain moderate, supporting a stable population and a complex of colonies with a moderate risk of a stochastic event impacting the population.

Guadalupe population – The smallest of the known populations, it is likely that this population would be significantly impacted by stochastic events. Due to its low numbers and spatial distribution, the probability of insect infestation causing mortality is relatively low; however, inability to recover from wildfire and to adapt climate variations places this population at relatively high risk. This small population appears to have limited floral resources, limited pollinator efficiency, and low connectivity between colonies, reducing the ability to successfully reproduce and therefore recover from threats. We predict that due to small population size and limited connectivity, overall condition of this population will remain poor, with low resiliency.

As discussed in Section IV.1.10, the projected climate changes forecast by the range of models and emissions scenarios will affect EFK survival in highly complex ways. And we do not know what the net result of beneficial and detrimental effects will be. However, we predict that EFK will be impacted minimally until a climatic severity threshold has been crossed. If this threshold is crossed, we predict the results would be decreased flowering and reproduction, causing a substantial population reduction.

The Recovery Plan (Service 1985: iii) established a recovery criterion of maintaining a stable protected population with at least 5,000 individuals, for 5 consecutive years, but did not show how this level was determined. However, we now understand that wildfire is able to devastate large, dense populations. We conclude that few large populations are much more vulnerable than many small populations, and that this recovery criterion should be amended.

The resilience of EFK derives not merely from the size of colonies, but also their density. Colonies that are too small or too isolated may incur loss of genetic diversity and inbreeding. Inversely, vulnerability to insect parasitism and rodent herbivory increases when colonies become too dense, or too large. Therefore, we believe that there must be some optimal range of meta-population density and colony size, although we do not currently know what those optima are. These concepts of colony size and density depend on how colony boundaries are delimited. The EO concept is a good starting point, but may have to be revised for EFK considering its specific population dynamics.

We can speculate that the population densities found on the small number of areas that have been quantitatively surveyed are representative of the entire global distribution of this subspecies. Based on all available evidence, we provisionally estimate that the global population size is about 20,000 individuals (Appendix B). Regardless of how this number is divided into colonies, we believe that it is likely that EFK has multiple, resilient populations.

VII.1.2. Representation

Representation refers to the genetic diversity, both within and among populations, necessary to conserve long-term adaptive capability (Shaffer and Stein 2000: 307–308).

Considering difference in habitat conditions, and variations among populations, EFK demonstrates its diversity and ability to adapt to environmental conditions. However, due to the EFK densities, gene flow among them may be easily disrupted. Therefore, maintaining the continuity of potential habitat throughout the subspecies range should have a high conservation priority. We recognize the need and recommend that genetic studies be conducted to determine the variation among populations, viability monitoring should be continued long enough to determine population dynamics and demographic trends at the colony and subspecies levels. Requirements, factors affecting survival and current conditions are summarized in Table 8.

Table 8. Summary of requirements, factors affecting survival, and current conditions of Kuenzler's hedgehog cactus individuals and populations, and the species' viability (representation, redundancy, and resilience).

INDIVIDUALS	POPULATIONS	SPECIES
Requirements of Kuenzler's hedgehog cactus		
• Suitable Habitat: Microsites of sparse vegetation over/near exposed limestone. • Reproduction: Sexual maturity at 4–5 years; fertilization requires genetic diversity within pollinator forage range. • Breeding system: Primarily out-crossing. • Pollinators: Megachilid bees; requires diverse native vegetation within forage range and low exposure to pesticides. • Seed ecology: Rodents may be seed-predators or seed-dispersers (or both). • Lifespan: Potentially at least 40 years.	• Stable or increasing demographic trends. • Sufficient genetic diversity to impart adaptive capability, low inbreeding, and sexual out-crossing. • Fire Cycle: Reduce juniper encroachment. • Distribution: Optimal population density is high enough to allow gene flow.	• Redundancy: Greater redundancy confers higher probability of enduring catastrophic events. • Representation: Greater genetic diversity confers more adaptive capability.

We believe that the three populations have a sufficient number of individuals, distributed across their ranges, with adequate connectivity to, provide for the representation needed to decrease the risk of extinction.

VII.2. Future Viability

We have considered what EFK needs for viability and current conditions of those needs (Section III), and we reviewed the stressors that are driving the historical, current, and future conditions of the species (Section IV). We now consider what the species' future conditions are likely to be. We apply our future forecasts to the concepts of resiliency, redundancy, and representation to describe the future viability of EFK.

We project what the viability of EFK could be under three scenarios. The "better than expected" scenario represents improvements over current conditions. The "moderate" scenario represents the most likely conditions if current trends continue. The "worse than expected" scenario represents deteriorating conditions. We describe, below, the relevant characteristics of these scenarios, and subsequently, their effects on populations. Table 15 summarizes our projections of the future species viability of EFK under each of these scenarios.

VII.2.1. Better than Expected Scenario

Under Better than Expected Scenario – Optimistically, we would expect EFK's viability to be characterized by higher levels of resiliency, representation, and redundancy than it exhibits under the current condition. The populations would be increase in overall condition, Northern Sacramento would remain in a high condition, Southern Sacramento would improve to high condition, and the Guadalupe would improve to moderate condition. Numerous colonies show stable or positive demographic trends. Genetic diversity within colonies remains sufficiently high for out-crossing to occur. Gene flow occurs regularly between colonies. The number of known, protected, managed, and resilient populations is sufficient to ensure long-term survival. Overall viability is high (Tables 9 and 10).

Northern Sacramento population – Numerous colonies show positive demographic trends; threats from wildfire are reduced, insect infestations are minimal, and climate change has no effect on EFK. This population would continue to have sufficient floral resources, pollinator availability, and high connectivity between colonies. Conditions will likely continue supporting a robust and stable population with a complex of dense colonies, able to withstand stochastic events.

Southern Sacramento population – Numerous colonies show stable or positive demographic trends. They continue to be threatened by a mild to moderate risk of wildfire, insect damage, and climate change. This population would improve to have sufficient floral resources, pollinator availability, and connectivity between colonies. Overall conditions will likely improve to good, supporting an increasing or stable population and a complex of colonies with a mild risk of a stochastic event impacting the population.

Guadalupe population – Numerous colonies show stable or positive demographic trends; Improved ability to recover from wildfire, and adapt climate variations. This small population would improve to have moderate floral resources, moderate pollinator efficiency, and moderate connectivity between colonies. Overall conditions will likely improve to moderate, supporting a stable population and a complex of colonies with a moderate risk of a stochastic event impacting the population.

a. Conservation support: Government agencies, nonprofit conservation organizations, and academic institutions collaborate and contribute resources to conserve EFK and its habitat. Development and management projects are evaluated and modified, if necessary, to avoid detriment to EFK and its habitat.

b. Surveys: Qualified botanists survey a large number of the highest-potential habitat throughout the species range. Both the presence and absence of EFK populations in this habitat contribute to improved understanding of the species' ecology, management, abundance, and true geographical range.

c. Geographic range: Several new extant EFK populations are documented throughout its range of potential habitat.

d. Habitat management: Extant populations are managed appropriately. This may include prescribed burning, juniper thinning, and other practices to maintain a high diversity of native plants, healthy pollinator populations and reduced fine fuels.

e. Population management: Extant colonies of EFK are monitored periodically to track demographic trends. Observed threats, such as wildfire, are prevented before populations are significantly impacted.

f. Climate changes: The effects of climate changes on EFK habitat are expected to be relatively minor, and well-tolerated by the species.

Table 9. *Echinocereus fendleri* var. *kuenzleri* population resiliency under the Better-than-Expected Scenario.

	Stressors to Population Resiliency			
Population	**Population Factors**			**Habitat Elements**
	Habitat Quantity	**Abundance**	**Reproduction**	**Connectivity**
Northern Sacramento	Reduced wildfire risks, Climate Change minimal effect	Insect impacts limited, Increased	Limited Insect impacts, Pollinator Efficiency	Reduced wildfire risk
Southern Sacramento	Wildfire risks reduced, Climate Change minimal effect, Livestock grazing with little to no effect	Insect impacts limited	Pollinator Efficiency	Wildfire, Small Population Size and density, Pollinator Efficiency
Guadalupe	Wildfire risks reduced, Climate Change minimal effect, Livestock grazing with little to no effect	Wildfire risks reduced, Insect impacts limited	Small Population Size and density, Pollinator Efficiency	Small Population Size and density, Pollinator Efficiency

Table 10. *Echinocereus fendleri* var. *kuenzleri* population resiliency rankings under the Better-than-Expected Scenario.

				Population Factors			Habitat Elements	
Population	**Sub-Population**	**Estimated Potential Habitat (acres)***	**Number of Cacti[1]**	**Habitat Quantity**	**Abundance**	**Reproduction**	**Connectivity**	**Overall Condition with Continuing Conditions**
Northern Sacramento	Vera Cruz	10,468	**56**	Moderate	Low	High	High	High
	Fort Stanton		**513**		High	High		
Southern Sacramento	Elk	14,715	**207**	Moderate	Moderate	High	Moderate	High
Guadalupe	Bullis	69,055	**2**	High	Low	High	Low	Moderate
	Prude		**5**		Low	High		
	Texas Hill		**8**		Low	High		

VII.2.2. Moderate Scenario (Continuing Current Conditions)

Under the Moderate Scenario – Continuing Current Condition. This scenario projects the condition of EFK's populations if the current risks to population viability continue with the same intensity as displayed currently. Appropriate management actions are sufficient for positive demographic trends. Genetic diversity within colonies remains sufficiently high for out-crossing to occur. Gene flow occurs regularly between colonies. Surveys are conducted on a portion of the highest-priority potential habitat, leading to improved understanding of habitat and geographic range, and allow an estimate of the number of known and unknown extant populations. Species survives but requires continued conservation, management, and protection (Tables 11 and 12).

Northern Sacramento population – This population has the most number of plants and highest density, mostly occurring on BLM and Forest Service managed lands; however they continue to be threatened by wildfire which increases mortality, insect damage reducing reproduction, and climate change. The removal of livestock grazing from a significant portion of this population habitat has increased the level of fine fuels, which increases the risk of catastrophic uncontrolled wildfire. It is projected that climate change may result increased periods of drought, increased average temperatures, decreased annual rainfall, and milder winters; however EFK has demonstrated adaptability to variations in environmental conditions. Large numbers, high connectivity and density in this population increase the risk of insect infestation. Assuming the parasitic insects are not newly-introduced species, EFK has been coevolving with them and is able to persist. This population appears to have sufficient floral resources, pollinator availability, and high connectivity between colonies. Therefore, we predict that over time, conditions will likely continue supporting a robust and stable population with a complex of dense colonies, able to withstand stochastic events.

Southern Sacramento population – This population represents roughly a quarter of the current EFK numbers and is currently stable. They continue to be threatened by a moderate risk of wildfire, insect damage, and climate change. It is projected that climate change may result increased periods of drought, increased average temperatures, decreased annual rainfall, and milder winters; however EFK has demonstrated adaptability to variations in environmental conditions. This moderately sized population appears to have moderate floral resources, moderate pollinator efficiency, and moderate connectivity between patches. We predict that over time, overall conditions will likely remain moderate, supporting a stable population and a complex of colonies with a moderate risk of a stochastic event impacting the population.

Guadalupe population – The smallest of the known populations, it is likely that this population would be significantly impacted by stochastic events. Due to its low numbers and spatial distribution, the probability of insect infestation causing mortality is relatively low; however, inability to recover from wildfire, and adapt climate variations places this population at increased risk. This small population appears to have limited floral resources, limited pollinator efficiency, and low connectivity between colonies, reducing the ability to successfully reproduce and therefore recover from threats. We predict that due to small population size and limited connectivity, overall condition of this population will remain low, with low resiliency.

a. Conservation support: Government agencies, non-profit conservation organizations, academic institutions, and private landowners collaborate and contribute some human and financial resources for conservation of EFK and its habitat. Public outreach has increased awareness of the species among private landowners and has generated increasing support for its conservation. Development projects are evaluated and modified, if necessary, to minimize or mitigate impacts to EFK and its habitat.

b. Surveys: Qualified botanists obtain access to survey a representative sample of the highest-potential habitat. Both the presence and absence of EFK populations in this habitat contributes improved understanding of the species' ecology, management, and true geographical range.

c. Geographic range: New extant EFK populations are documented within the range of potential habitat.

d. Habitat management: At least some extant populations are managed appropriately. This may include prescribed burning, juniper thinning, and other practices to maintain a high diversity of native plants and healthy pollinator populations.

e. Population management: At least some extant populations of EFK are monitored periodically to track demographic trends. Observed threats, such as juniper encroachment, are prevented before populations are significantly impacted. Small, declining populations are monitored to see if they recover spontaneously.

f. Climate changes: Climate changes have minor impacts on EFK habitat, but with appropriate management the species' overall status remains stable.

Table 11. *Echinocereus fendleri* var. *kuenzleri* population resiliency under the Continuing Current Conditions Scenario.

	Stressors to Population Resiliency			
Population	**Population Factors**			**Habitat Elements**
	Habitat Quantity	**Abundance**	**Reproduction**	**Connectivity**
Northern Sacramento	Wildfire risks continue, Moderate Climate Change effects	Wildfire risks continue, Moderate Climate Change effects, Insect infestation	Insect infestation, Pollinator efficiency	Wildfire
Southern Sacramento	Wildfire risks continue, Moderate Climate Change effects, Minimal livestock grazing impacts	Wildfire risks continue, Moderate Climate Change effects, Minimal livestock grazing impacts	Small Population Size and density, Pollinator Efficiency	Wildfire, Small Population Size and density, Pollinator Efficiency
Guadalupe	Wildfire risks continue, Moderate Climate Change effects, Minimal livestock grazing impacts	Wildfire risks continue, Moderate Climate Change effects, Minimal livestock grazing impacts	Small Population Size and density, Asynchronous flowering, Pollinator Efficiency	Small Population Size and density, Pollinator Efficiency

Table 12. *Echinocereus fendleri* var. *kuenzleri* population resiliency rankings under the Continuing Current Conditions Scenario.

				Population Factors			Habitat Elements	
Population	**Sub-Population**	**Estimated Potential Habitat (acres)***	**Number of Cacti[1]**	**Habitat Quantity**	**Abundance**	**Reproduction**	**Connectivity**	**Overall Condition with Continuing Conditions**
Northern Sacramento	Vera Cruz	10,468	**56**	Moderate	Low	Moderate	High	High
	Fort Stanton		**513**		High	High		
Southern Sacramento	Elk	14,715	**207**	Moderate	Moderate	Moderate	Moderate	Moderate
Guadalupe	Bullis	69,055	**2**	High	Low	High	Low	Moderate
	Prude		**5**		Low	Low		
	Texas Hill		**8**		Low	Moderate		

VII.2.3. Worse than Expected Scenario

We would expect EFK's viability to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. The Northern Sacramento population would be in moderate condition, Southern Sacramento population would be in low condition, and Guadalupe population would likely become extirpated. Therefore, we would expect only the Northern and Southern Sacramento populations, to persist under adverse conditions. The Guadalupe population would be unlikely to persist. EFK would decline toward extinction in this scenario (Tables 13 and 14).

<u>Northern Sacramento population</u> – This population would decline and would continue to be threatened by wildfire which increases mortality, insect damage reducing reproduction, and climate change. This population's floral resources, pollinator availability, and connectivity between colonies would decrease. Conditions will likely decline to moderate, resulting in a declining population, reducing its ability to adapt and withstand stochastic events.

<u>Southern Sacramento population</u> – This population would decline with increased risks of catastrophic wildfire, insect damage, and climate change. This moderately sized population would decline to have moderate floral resources, moderate pollinator efficiency, and moderate connectivity between patches. Overall conditions will likely diminish to low, resulting in a declining population unable to support a complex of colonies with a high risk of a stochastic event impacting the population.

<u>Guadalupe population</u> – The smallest of the known populations, it is likely that this population would be significantly impacted by stochastic events. Due to its low numbers and spatial distribution, the probability extirpation is high; inability to recover from wildfire, and adapt climate variations places this population at increased risk. This small population would have limited floral resources, limited pollinator efficiency, and low connectivity between colonies, reducing the ability to successfully reproduce and therefore recover from threats. We predict that due to small population size and limited connectivity, this population would cease to exist.

a. Conservation support: Government agencies, nonprofit conservation organizations, academic institutions, and private landowners fail to collaborate or contribute sufficient human and financial resources to conserve extant EFK populations and high-potential habitat. Landowners remain largely unaware of the species and are unsupportive of its conservation. Development projects significantly impact EFK and its habitat.

b. Surveys: Qualified botanists are unable to access representative samples of the highest-potential habitat. Nothing new is learned about the species' ecology, management, and true geographical range.

c. Geographic range: No new extant EFK populations are documented, or if additional populations are found, they cannot be protected or conserved.

d. Habitat management: Known extant populations are not managed appropriately.

e. Population management: Known extant populations of EFK are not monitored periodically.

f. Climate changes: Climate changes have severe impacts on EFK habitat and the species' overall status declines.

Table 13. *Echinocereus fendleri* var. *kuenzleri* population resiliency under the Worsening Conditions Scenario.

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	Stressors to Population Resiliency			
Population	**Population Factors**			**Habitat Elements**
	Habitat Quantity	**Abundance**	**Reproduction**	**Connectivity**
Northern Sacramento	Wildfire, Climate Change effects severe, Insect infestation	Wildfire, Climate Change effects severe	Insect infestation, Pollinator efficiency	Wildfire
Southern Sacramento	Wildfire, Climate Change effects severe, Livestock grazing	Wildfire, Climate Change effects severe, Livestock grazing	Small Population Size and density, Pollinator efficiency	Wildfire, Small Population Size and density, Pollinator efficiency
Guadalupe	Wildfire, Climate Change effects severe, Livestock grazing	Wildfire, Climate Change effects severe, Livestock grazing, Illicit collection	Small Population Size and density, Pollinator efficiency Illicit collection	Small Population Size and density, Pollinator efficiency

Table 14. *Echinocereus fendleri* var. *kuenzleri* population resiliency rankings under the Worsening Conditions Scenario.

				Population Factors			Habitat Elements	
Region	**Population**	**Estimated Potential Habitat (acres)***	**Number of Cacti[1]**	**Habitat Quantity**	**Abundance**	**Reproduction**	**Connectivity**	**Overall Condition with Worsening Conditions**
Northern Sacramento	Vera Cruz	10,468	**56**	Moderate	Moderate	Low	Moderate	Moderate
	Fort Stanton		**513**		High	Moderate		
Southern Sacramento	Elk	14,715	**207**	Moderate	Moderate	Low	Low	Low
Guadalupe	Bullis	69,055	**2**	High	Low	Low	Low	Low
	Prude		**5**		Low	Low		
	Texas Hill		**8**		Low	Low		

Table 15. Future species viability under a range of scenarios.

Viability Elements	Scenarios		
	Better than Expected	Moderate	Worse than Expected
Population Resilience	Numerous colonies show stable or positive demographic trends.	Appropriate management, augmentation, and reintroduction (as appropriate) are sufficient for positive demographic trends.	Public and private landowners are unable or unwilling to protect other extant populations.
Species Representation	Genetic diversity within colonies remains sufficiently high for out-crossing to occur. Gene flow occurs regularly between colonies.	Genetic diversity within colonies remains sufficiently high for out-crossing to occur. Gene flow occurs regularly between colonies.	Portions of the species' global population are destroyed, and overall genetic variation and gene flow decline.
Species Redundancy	The number of known, protected, managed, and resilient populations is sufficient to ensure long-term survival.	Surveys are conducted on a portion of the highest-priority potential habitat, lead to improved understanding of habitat and geographic range, and allow an estimate of the number of known and unknown extant populations.	The known, extant populations are declining, or cannot be protected and managed.
Overall Viability	High	Species survives but requires continued conservation, management, and protection.	Declining toward extinction.

VIII. Recommendations

1) Establish a quantitative monitoring program for all populations to measure trends over time.

2) Obtain sufficient demographic information to complete a population viability analysis.

3) Complete a genetic analysis to determine if the taxon is valid and if population areas represent true populations.

4) Develop habitat management plans for the EFK with each major land management agency. The EFK is a conservation-reliant species that will require long-term management even if delisted (Scott et al. 2005: 386).

5) Ground truth the habitat suitability model and density estimates to improve accuracy and develop protocol to determine where to look for additional populations.

6) Develop an updated recovery plan to clearly define when delisting is appropriate.

7) Identify private lands with important EFK populations, and work with landowners to develop conservation agreement to protect the EFK.

8) Develop public outreach to increase awareness of the species among private landowners and generated increasing support for its conservation.

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X. Acronyms Used

EO	Element Occurrence
ESA	Endangered Species Act
FR	Federal Register
GIS	Geographic Information System
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
SSA	Species Status Assessment
SERVICE	United States Fish and Wildlife Service
USGS	United States Geological Survey

Appendix A. Glossary of Scientific and Technical Terms.

Term	Definition
Areole	Specialized axillary bud or short shoot in cactus species; the spine cushion, producing leaves, spines, and flowers.
Breeding System	The ability of a plant species to reproduce via outcrossing, self-fertilization, apomixis, or a combination.
Central spines	One of the innermost spines of an areole.
Chihuahuan Desert	Arid region between the Sierra Madre Oriental and Sierra Madre Occidental of northern Mexico, extending into southwest Texas and southern New Mexico of the U.S.
Demography	Scientific study of populations.
Element Occurrence	An area of land or water in which a species or natural community is, or was, present.
Endangered	"…any species which is in danger of extinction throughout all or a significant portion of its range other than a species of the Class Insecta determined by the Secretary to constitute a pest whose protection under the provisions of this Act would present an overwhelming and overriding risk to man."
Endemic	An organism restricted to a specific habitat or geographic range.
Evaporative deficit	The difference between actual and potential evapotranspiration.
Forb	A broad-leafed herbaceous plant.
Genetic bottleneck	An event which greatly restricts an organism's genetic diversity.
Genetic drift	A change in allele frequencies within a population over time.
Greenhouse gas	Gases such as carbon dioxide, water vapor, and methane that contribute to the atmosphere's thermal insulation through absorption of light in the infra-red spectrum.

Inbreeding	Sexual reproduction between closely-related individuals.
Inbreeding depression	The reduction of fitness caused by mating between relatives.
Loam	Soil containing moderate amounts of sand, silt, and clay.
Meta-population	A group of spatially separated populations of the same species that interact at some level.
Micro-habitat	Very specific or fine-scale portion of a habitat that is occupied by a species.
Microsite	Micro-habitat.
Neotenous	retention of some immature characters in adulthood
Outcross	In plants, sexual fertilization involving the union of gametes from different individuals.
Phenology	Seasonal pattern of plant growth, development and reproduction.
Population	Collection of inter-breeding organisms of a particular species.
Population dynamics	Changes in the size and age composition of populations over time, and the biological and environmental processes influencing those changes.
Radial spines	One of the outermost spines of an areole, often radiating or appressed.
Recruitment	Addition of new individuals to a population.
Redundancy	The number of populations or sites necessary to endure catastrophic losses.
Reintroduction	Restoration of populations of a species where it is currently absent but within its former range and habitat.
Representation	The genetic diversity necessary to conserve long-term adaptive capability.
Resilience	The size of populations necessary to endure random environmental variation.
Savanna	Mosaic of trees or shrubs and grassland; between 40 percent and 10 percent cover by trees and shrubs.
Section 6	Cooperative Endangered Species Conservation Fund (Section 6 of the ESA).
Section 7	The section of the Endangered Species Act of 1973, as amended, outlining procedures for interagency cooperation to conserve Federally listed species and designated critical habitat.
Self-fertilization	Sexual reproduction involving the union of gametes from a single individual.

Speciation	The evolutionary process by which new biological species arise.
Species viability	A species' ability to sustain populations in the wild beyond the end of a specified time period, assessed in terms of its resilience, redundancy, and representation.
Stochastic	Random.
Subspecies	A taxonomic group that is a division of a species; usually arises as a consequence of geographical isolation within a species.
Synecology	Ecology of groups of coexisting organisms.
Taxon	(Plural, taxa). A natural group of organisms at any rank in the taxonomic hierarchy.
Taxonomy	Scientific classification of living organisms.
Tepal	Sterile leaflike structure of the flower when the perianth parts are not differentiated into sepals and petals.
Threatened	"…any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range."
Tubercle	A conical or cylindrical outgrowth or protuberance from a cactus stem, usually bearing all or part of the areole; podarium.
Vegetative cover	The proportion of an area that is intercepted vertically by tissues of a specified taxon or type of plants; total cover may exceed 1 due to multiple layers.
Woodland	Vegetation type with discontinuous tree cover.

Appendix B. Estimate of potential habitat and population size for Kuenzler's hedgehog cactus

Introduction

Our primary purpose for creating a habitat suitability model is to provide a reasonable population estimate. While other uses of the model output are plausible, such applications should be employed with great care. The additive effects of parameter-based error rates, resolution differences, errors and uncertainty in the observation data, as well as unknowns surrounding the ecology of EFK, are key factors that add to overall model uncertainty. In addition, there has been no *formal* accuracy assessment performed and thus probabilities of detection are generally unknown and should not be inferred. In other words, the spatial model output (suitable habitat polygons) should only be viewed or used as a heuristic guide and not as a definitive binary or probability-based determination of presence or absence; field validation is always warranted and strongly encouraged with any habitat suitability model.

Model Overview

In order to estimate a population size, we constructed a deterministic habitat suitability model using four abiotic characteristics strictly derived from known observations. The characteristics (i.e., model parameters) used in creating the model were: occupied soil map units (SSURGO 2014), elevation, aspect, and slope. Elevation information was extracted from the National Elevation Dataset (NED) ⅓-arc-second (approximately 10 m [33 ft] ground surface distance [GSD] resolution) seamless digital elevation model (DEM; U.S. Geological Survey 2012). Aspect and slope rasters (a gridded data format) were in turn derived from the NED DEM with units of measure of degrees. Lastly, final model output was clipped with PRISM 30-year precipitation normals (1981–2010) at the 406.4 mm (16 in) annual isopleth (PRISM 2017; BEEC 2002: 27; NMEMNRD 1989: 91). All observation data were supplied by Natural Heritage New Mexico (NHNM 2016: entire). All geoprocessing was carried out with ArcGIS 10.4.1 (ESRI 2016).

We modeled each population (Northern Sacramento, Southern Sacramento, and Guadalupe) separately. Therefore we parsed the NHNM observation data geographically and grouped all Element Occurrences (EOs) accordingly. The total number of EOs in each population is as follows:

Northern Sacramento = 1,846
Southern Sacramento = 181
Guadalupe = 322

An EO is a spatial element that can contain multiple observations (individuals). During data entry, the total count of observations for a given EO is recorded in the <TotalLastCount> field; however, particularly for older data, the number of observations may not have been recorded or the relative confidence in the count precludes their entry into the database (NatureServe 2017). Such records have a *Null* value. Conservatively setting the Null records equal to 1, the total number of individuals for each population is as follows:

Northern Sacramento = 2,905
Southern Sacramento = 647
Guadalupe = 844

These totals are for all years contained in the database (1978–2015). For a variety of reasons, it is not realistic to consider these values as an accurate population estimate. Conversely, however, the location of even the oldest of the records is useful in delineating an area that is suitable habitat. Therefore, the habitat suitability model does not use the observation counts per se but rather the spatial representation of the EOs, which are polygons of varying sizes that reflect the locational uncertainty of the data collected in the field.

Model Parameter Definitions

Soils

SSURGO soils data (vector format) was downloaded for each 8-digit Hydrologic Unit Code (HUC8; Watershed Boundary Dataset 2017) that contained an EO. We then intersected the soils data with each population's EO dataset to identify occupied soil map units. The intersected soil map units (occupied soil types) were then exported and used to create a population-specific query to select all corresponding polygons within the larger soils layers (see Tables B1–B3). The result of these queries were then exported and used as a starting point for the habitat suitability model.

Table B1. Northern Sacramento population occupied soil map units.[1]

Map Unit	Geomorphic Description
Tortugas-Asparas-Rock outcrop association, moderately sloping	Hillslopes, uplands
Tortugas-Rock outcrop association, extremely steep	Hills, ridges
Clovis-Harvey association, gently sloping	Piedmonts, valley sides
Deacon loam, 0 to 8 percent slopes	Hillslopes, plains
Dioxice loam, 2 to 5 percent slopes	Plains, valley sides
Hightower-Oro Grande complex, moderately steep	Swales, uplands
Hightower variant sandy loam, 3 to 8 percent slopes	Ridges, uplands
Mokiak-Stroupe-Rock outcrop association, very steep	Mountain slopes, mountains
Nogal-Rock outcrop complex, moderately steep	Hillslopes, uplands
Pena-Dioxice complex, moderately sloping	Plains, valley-floor remnants
Plack-Dioxice loams, 0 to 8 percent slopes	Mesas, plains
Reventon loam, 3 to 8 percent slopes	Valley sides, valleys

Romine extremely gravelly loam, 15 to 45 percent slopes	Alluvial flats, plains
Stroupe bouldery sandy clay loam, extremely steep	Hillslopes, plains
Tortugas-Rock outcrop association, extremely steep	Hillslopes, uplands
Travessilla-Rock outcrop association, moderately sloping	Hills, ridges

[1]Soil types use percent slope and GIS derived slope are in degrees.

Table B2. Southern Sacramento population occupied soil map units.

Map Unit	Geomorphic Description
Deama-Rock outcrop complex	Hills, hillslopes, low hills
Ector-Rock outcrop complex, 0 to 9 percent slopes	Hills, hillslopes, low hills
Ector-Rock outcrop complex, 9 to 30 percent slopes	Hills, hillslopes, low hills
Remunda-Penasco association	Alluvial fans, uplands, valley sides

Table B3. Guadalupe population occupied soil map units.

Map Unit	Geomorphic Description
Deama gravelly loam, 0 to 5 percent slopes	Hills, mesas, ridges
Deama gravelly loam, 5 to 30 percent slopes	Hills, ridges
Deama-Rock outcrop complex	Hills, hillslopes, low hills
Deama-Rock outcrop complex, 50 to 150 percent slopes	Canyons, hills
Ector stony loam, 0 to 9 percent slopes	Hills, ridges, uplands
Ector-Rock outcrop complex, 20 to 50 percent slopes	Hills, mesas
Limestone rock land	–
Montecito loam, 0 to 10 percent slopes	Alluvial fans, piedmonts
Rock outcrop-Deama complex, 40 to 150 percent slopes	Hills
Rock outcrop-Lozier complex, 20 to 65 percent slopes	Hills
Tortugas cobbly loam, 5 to 30 percent slopes	Hills, ridges

While there is some variation of soil types among and across the three populations, there appears to be two common themes. First, most map units have some slope associated with them and are located in geomorphic areas of notable topographic relief (i.e., hills, canyons, piedmonts, etc.). This generally agrees with the slope parameter described below. Second, many map units have a rocky component or are gravelly loams associated with erosional/depositional processes.

Elevation, Aspect, and Slope

To determine the values for each of these parameters, the mean value for each EO from the three populations was extracted from the individual rasters and plotted in a frequency distribution (Figures 2-4). We then selected the appropriate ranges of each model parameter (elevation, aspect, and slope) to capture 80-90 percent of the frequency distribution which identifies a central tendency without including outliers. This is a more conservative approach as it selects a representative sample of occupied/favorable habitat, in terms of each parameter, while limiting the total area. Elevation for the Guadalupe population was bimodal and therefore exceeded the 90 percent threshold (see below). The model parameter intervals are as follows:

Northern Sacramento Population

> Elevation range = 1,980-2,129 m (6,496-6,985 ft); 89.2 percent of the frequency distribution;
> Aspect range = 67.6-202.5 degrees (east to south); 89.0 percent of the frequency distribution;
> Slope range = 5.6-25.5 degrees; 88.5 percent of the frequency distribution.

Southern Sacramento Population

> Elevation range = 1,850-1,974 m (6,070-6,476 ft); 91.4 percent of the frequency distribution;
> Aspect range = 67.6-247.5 degrees (east to southwest); 85.1 percent of the frequency distribution;
> Slope range = 4.1-18 degrees; 84.5 percent of the frequency distribution.

Guadalupe Population

> Elevation range = 1,559-1,683 m (5,115-5,521 ft) and 1,734-1,858 m (5,689-6,096 ft); 95.7 percent of the frequency distribution;
> Aspect range = 22.6-247.5 degrees (northeast to southwest); 89.5 percent of the frequency distribution;
> Slope range = 0.3-10.2 degrees; 89 percent of the frequency distribution.

The elevation, aspect, and slope rasters were then converted to vector polygons. This was a practical approach as the soils data, which more broadly defines areas of suitable habitat, was in vector format and would be further refined by each of the additional parameters described above. After the raster-to-vector conversion, queries were made to select the intervals defined above and the results exported in order to clip the soils layers. This clipping process produced the final suitable habitat polygons. The suitable habitat area for each population is as follows:

Northern Sacramento = 10,468 acres
Southern Sacramento = 14,715 acres
Guadalupe = 69,055 acres
Total = 94,238 acres

Again, it is important to note that the defined suitable habitat is ultimately limited to the occupied HUC 8s where known observations occurred. Suitable habitat and additional plants may exist outside these areas.

Population Estimate

The final population estimate was obtained by multiplying the modeled area of suitable habitat (above) by an estimated density value. We used only 2012 observation data in the density estimate to avoid double counting and potentially overestimating a density value by including previously surveyed plants that are no longer present. Unfortunately, we did not have any survey effort data to couple with the observations thus our density estimate is based on what appeared to be a natural grouping of individuals within each population. This is a subjective process. Ultimately, however, after a number of trials, we settled on an intermediate level of grouping (through a minimum bounding geometry – convex hull) that produced the following mean density values:

Northern Sacramento = 0.77 plants per acre
Southern Sacramento = 0.31 plants per acre
Guadalupe = 0.12 plants per acre

Using these values, the final population estimate is (number of plants):
Northern Sacramento = 8,025
Southern Sacramento = 4,617
Guadalupe = 8,007
Total = 20,649 (or ≈ 20,000)

We consider this a fairly conservative estimate for the following reasons: 1) the model is artificially limited to the HUC8s where known observations occurred; 2) the parameter data (elevation, aspect, and slope) was limited to omit outliers and thus reduce the total area delineated; 3) the final model was clipped by the PRISM 406.4 mm (16 in) annual isopleth (NMEMNRD 1989: 91; PRISM 2017: 4) we used only 2012 observation data in our density estimates; and 5) although subject to interpretation, our characterization (grouping) of plant densities was an intermediate value.

In 2017 Bureau of Land Management and U. S. Fish and Wildlife Service staff conducted a comprehensive survey within the Northern Sacramento population area (Davidson 2017: entire). Termed the "Outlaw Trail Survey", this effort provided 69 new locations and an accurate account of survey effort (190.5 ha [470.7 acres]) through global positioning system (GPS) tracks. The supplied data indicated the total plants at each location ranged from 1-10. For our purposes here, however, we conservatively deem each location as having a single cactus. Although only a single survey, this effort allowed for an *informal* accuracy assessment of the habitat suitability model's performance. Results showed that 64 percent of the new observations fell within predicted suitability model polygons. When a 10 m (33 ft) buffer was added to the new observations the locational accuracy increased to 77 percent.

We stress that this is only a cursory examination of the model and should not in any way be construed as a *formal* account or test of model accuracy or precision. Further, the Outlaw Trail Survey occurred in an area with known observations and is therefore biased to some degree. Nonetheless, the model showed an encouraging level of parameter fidelity as new observations tended to fall within polygons identified as suitable and predicted non-suitable areas tended not have new observations.

An additional benefit from the Outlaw Trail Survey allowed for an *informal* test of our population density estimate. Again, this is a single survey effort which was not stratified nor did it include areas outside known occupation; however, the density value derived here is at least some validation of the assumptions we have previously employed to estimate the EFK population.

If the Outlaw Trail Survey data is used to derive a density value for the Northern Sacramento population the density estimate falls to 0.15 plants per acre, substantially less than the original estimate of 0.77 plants per acre. This results in a Northern Sacramento population estimate of 1,534 plants. In an effort to be even more conservative in the population estimate, we used the lowest calculated population density value of 0.12 plants per acres for the Southern Sacramento population as well. This results in a Southern Sacramento population estimate of 1,765. We therefore estimate a total EFK population of between 11,000-20,000 plants.

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